European Journal of Pain

ORIGINAL ARTICLE OPEN ACCESS

Temporal Associations of Physical Activity With Subsequent Knee Pain in Individuals With Knee Osteoarthritis: An Ecological Momentary Assessment Study

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Received: 2 December 2024 | **Revised:** 8 April 2025 | **Accepted:** 9 April 2025

Funding: Kristian Kjær-Staal Petersen acknowledges funding from the Center for Neuroplasticity and Pain (CNAP), supported by the Danish National Research Foundation (DNRF121), and the Center for Mathematical Modeling of Knee Osteoarthritis (MathKOA), funded by the Novo Nordisk Foundation (NNF21OC0065373).

Keywords: accelerometer | ecological momentary assessment | knee osteoarthritis | knee pain | physical activity | temporal associations

ABSTRACT

Background: Physical activity (PA) is a first-line treatment for knee osteoarthritis and provides benefits for functional improvement and pain relief. However, movement-evoked pain often hinders PA participation and long-term adherence. The relationship between PA and pain is not fully understood and may vary across individuals. We examined the temporal associations between PA and subsequent knee pain in individuals with knee osteoarthritis.

Methods: In a 10-day ecological momentary assessment (EMA) cohort study, PA was recorded using an Actigraph accelerometer; momentary knee pain intensity was rated on a numeric rating scale in responses to four daily text prompts. Linear mixed-effects models examined within-day and between-day associations between PA and knee pain, adjusting for age, sex and BMI.

Results: The sample included up to 454 observations across 10 days from 17 participants (age $= 64 \pm 7$ years, BMI $= 27 \pm 4$ kg/m^2, 61% women), each consisting of a temporal pair of PA minutes and subsequent momentary pain. Within-day, greater moderate-to-vigorous PA (MVPA) minutes were associated with a subsequent increase in knee pain (adjusted $\beta = 0.112$, 95% CI: 0.023, 0.201, $p = 0.014$); while light-intensity PA showed no association with subsequent pain (adjusted $\beta = -0.003$, 95% CI: -0.011, 0.005, $p = 0.461$). Current-day MVPA and light-intensity PA minutes were not associated with next-day knee pain.

Conclusions: While MVPA may temporarily increase knee pain, its impact was transient. Light-intensity PA showed no association with pain, suggesting it may be a suitable alternative for those with movement-evoked pain. Understanding these temporal patterns can help guide tailored pain management and PA adherence strategies. Further research is needed to confirm these preliminary findings.

Significance Statement: Understanding the dynamic relationship between PA and knee pain is crucial for optimising the management of knee OA. This exploratory study offers new insights by leveraging high-frequency data to examine the intra- and inter-day associations of MVPA and light-intensity PA with subsequent knee pain. The preliminary findings demonstrate that MVPA may lead to transient pain increases, while light-intensity PA is not associated with pain intensity. Identifying these PA-pain temporal patterns can inform personalised strategies for pain management and improving long-term activity adherence.

1 | Introduction

Knee osteoarthritis (OA) is a prevalent chronic condition characterised by joint pain, stiffness and functional impairment (Hunter and Bierma-Zeinstra 2019). It significantly diminishes the quality of life for millions of people worldwide, affecting individuals across low-, middle- and high-income countries (GBD 2017, Disease and Injury Incidence and Prevalence Collaborators 2018). Physical activity (PA) is a core management strategy for knee OA (Bannuru et al. 2019; Kolasinski et al. 2020; Moseng et al. 2024). However, movement-evoked pain often limits PA participation and poses challenges to long-term adherence (Corbett et al. 2019; Leemans et al. 2022).

Qualitative studies have shown that movement-evoked pain is a common barrier to regular PA (Murphy et al. 2015; Thomas et al. 2019), often creating a perceived vicious cycle where both PA and pain limit each other (Hendry et al. 2006; Holden et al. 2009; Wilcox et al. 2006). Although PA may initially trigger pain, continued engagement could ultimately lead to relief (Butera et al. 2016, 2024; Hodges and Smeets 2015). Conversely, reducing the amount and/or intensity of PA may be necessary to alleviate symptoms following flare-ups (Butera et al. 2016, 2024; Hodges and Smeets 2015). The interaction between PA and pain is likely dynamic, varying over the course of a day, week or month (Allen et al. 2009; Parry et al. 2019). However, high-frequency quantitative evidence capturing these intra- and inter-day dynamics between PA and pain is lacking.

Conventional studies (Chang et al. 2023; Liu et al. 2016; Song et al. 2018) on the PA-pain relationship often rely on retrospective self-reports or low-frequency sampling, which are prone to recall biases and may not capture the variability and immediacy of pain experiences and PA behaviours. Ecological momentary assessment (EMA) addresses this limitation by collecting high-frequency data several times daily in participants' natural living environment, reducing recall biases and enhancing ecological validity (May et al. 2018; Shiffman et al. 2008). While EMA is resource-intensive and may increase participant burden—potentially excluding individuals unwilling or unable to commit to a demanding protocol—it enables real-time, high-resolution tracking of pain and PA, capturing nuances that traditional methods may miss. This approach provides objective, granular insights into their temporal dynamics, supporting future development of personalised, adaptive PA programmes to better manage knee OA symptoms and promote sustained PA engagement.

In this exploratory EMA study, we aimed to examine (1) the within-day temporal associations of PA levels with immediate subsequent knee pain intensity, and (2) the between-day temporal associations of current-day PA levels with next-day knee pain intensity.

2 | Methods

2.1 | Study Design

This is a cohort study, using EMA to explore the temporal associations of PA with subsequent pain intensity. Ethical approval was granted by the local ethics committee in the North Denmark Region (N-20220047). All participants received written and oral information prior to providing informed consent to participate in the study.

2.2 | Study Participants

Older adults with knee OA participated in this study. Recruitment sources included general practitioners (GPs) and physiotherapists in the North Denmark Region, Aalborg University Hospital, ReumaNord and social media (e.g., Facebook and Twitter) postings. The inclusion criteria were based on the NICE (National Institute of Health and Care Excellence) Guideline, one of the most commonly applied criteria for knee OA in primary care (Skou et al. 2020). Inclusion criteria were (1) men or women aged 45–75 years; (2) BMI $\leq 35\,kg/m^2$; (3) frequent movement-related knee pain (knee pain on more than half the days of the past month); (4) no or lasting $<$30-min morning stiffness; (5) self-reported unilateral or bilateral mild-to-moderate knee pain (≥ 3 and ≤ 7 on a 0–10 numeric pain rating scale [NPRS]) (Boonstra et al. 2014) to exclude individuals with very mild symptoms unlikely to fluctuate, as well as those with severe pain that could limit their ability to engage in daily PA; (6) knee pain duration $\geq$12 months; (7) physically able to walk unassisted on a treadmill at $\geq$4 km/h for 30 min; (8) own a smartphone; (9) willing and able to wear an activity monitor and answer electronic survey questions delivered via a smartphone over 10 days. The NICE committee (NICE Guideline 2022) recommends diagnosing OA clinically without imaging for individuals aged 45 and older with activity-related joint pain and minimal morning stiffness, citing no clear evidence supporting the benefits of imaging. The NICE criteria effectively identified 89% of patients treated for knee OA in primary care, supporting their validity (Skou et al. 2020).

Exclusion criteria were (1) intra-articular steroid injections in the previous 3 months; (2) intra-articular hyaluronic acid injection in the previous 6 months; (3) any arthroscopic or surgical knee procedures (e.g., partial meniscectomy) in the past 12 months; (4) lumbar radiculopathy; (5) neurological, vestibular, or visual dysfunction affecting walking balance and mobility; (6) plan for total knee arthroplasty in the next 12 months to exclude individuals with end-stage disease and significant functional limitations.

Experienced physiotherapists interviewed potential participants by phone using a standardised screening form to assess eligibility.

2.3 | Demographic, Health-Related and Knee-Specific Characteristics

Participants reported demographic information (age, sex, body weight/height), chronic health conditions (e.g., hypertension, heart disease, diabetes, cancer), pain medication use for knee pain in the past month, and pain in other body regions. Pain catastrophizing was assessed using the 13-item Pain Catastrophizing Scale (PCS; range 0–52) (Sullivan et al. 1995). PCS evaluates Rumination, Magnification and Helplessness subscales and is validated in chronic pain populations (Osman

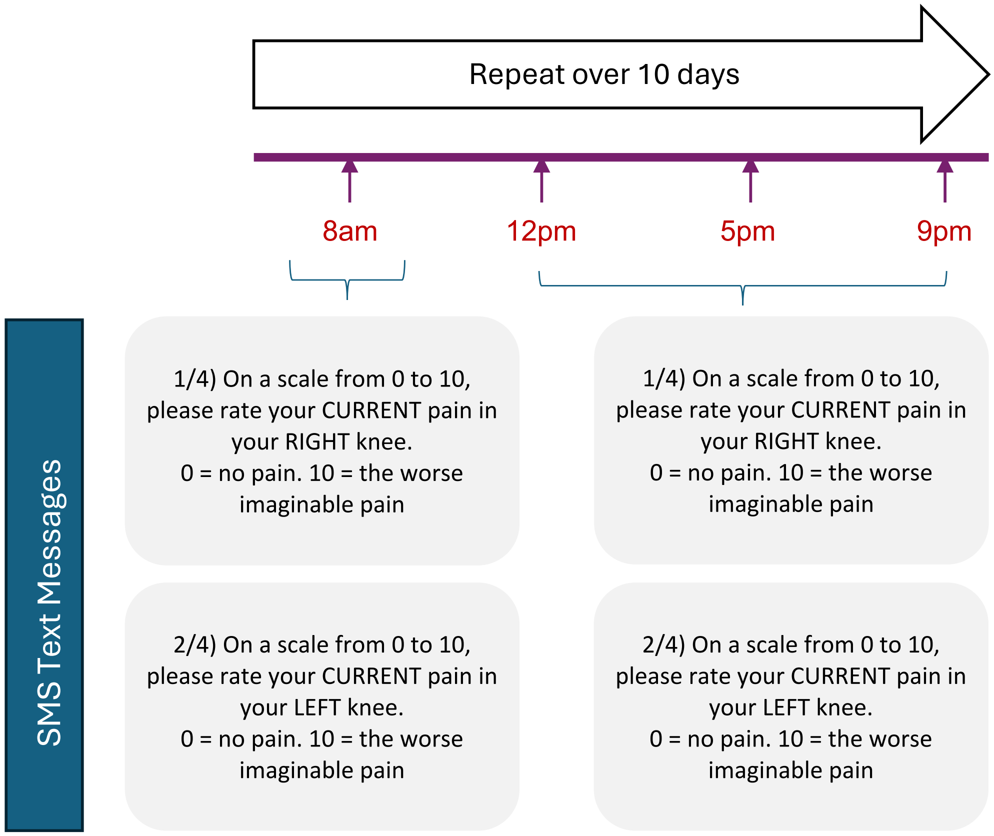

FIGURE 1 | Schematic chart for assessing momentary knee pain. The intensity of right and left knee pain was separately queried 4 times per day over 10 continuous days, using SMS text messages delivered to participants' smartphones.

et al. 2000), including in Danish cohorts (Kjøgx et al. 2014). Sleep quality was measured using the Pittsburgh Sleep Quality Index (PSQI; range 0–21) with higher scores indicating worse sleep (Buysse et al. 1989). The PSQI has strong reliability and validity (Mollayeva et al. 2016), including in Danish populations (Ørskov and Norup 2022). The more symptomatic knee was designated as the study knee (right knee if symptoms were equal). Participants reported knee symptom duration, worst pain in the past week, and pain after 30 min of walking using the Numeric Pain Rating Scale (NPRS, range 0–10) (Dworkin et al. 2005). Knee function and quality of life were evaluated using the Knee Injury and Osteoarthritis Score (KOOS), a 42-item questionnaire with 5 subscales (Pain, Symptoms, Activity of Daily Living [ADL], Sport/Recreation, Quality of LIfe [QoL]) (Roos et al. 1998). Scores are normalised to 0–100, with higher scores indicating better outcomes. KOOS demonstrates strong reliability and validity in individuals with knee injuries or OA (Collins et al. 2016).

2.4 | Momentary Pain Intensity by Text Messages

We used a signal-contingent approach (May et al. 2018), where participants completed surveys in response to a prompt (i.e., a text message). Participants received 4 text prompts in Danish per day to answer a series of questions, delivered and recorded through an SMS system (www.sms-track.com, Aarhus, Denmark). To balance the need for collecting fine-grained data with minimal participant burden, the recommended EMA sampling frequency for adults with chronic pain is 3 to 5 times per day (May et al. 2018). As shown in Figure 1, momentary pain of the right and left knee was separately assessed using the NPRS (range: 0–10), which has excellent reliability and validity for adults with chronic musculoskeletal pain (Alghadir et al. 2018; Ferreira-Valente et al. 2011). A reminder text was sent 30 min after the initial message if no response was received.

2.5 | Momentary Physical Activity by Actigraph Accelerometer

Following a standardised script, research personnel instructed participants on how to wear an Actigraph accelerometer (Actigraph GT3X-BT, Pensacola, FL, USA) on their non-dominant wrist for 24 h over 10 continuous days. Participants were instructed to keep the device on while showering, bathing, and swimming, and to only remove the device if it would be submerged in water for more than 30 min. In such a case, they were instructed to put the device back on immediately afterward. At the end of the 10th day, participants returned the accelerometer using a pre-paid envelope provided to them. The wrist-worn Actigraph Accelerometer has been employed in the UK Biobank study (Barker et al. 2019; Doherty et al. 2017) and the US National Health and Nutrition Examination Survey (NHANES) (National Health Examination and Nutrition Survey 2011; Shim et al. 2023), due to its advantages in reducing non-wear time, minimising participant burden, and promoting compliance (Freedson and John 2013; Troiano et al. 2014). It has demonstrated good reliability and validity for measuring PA in free-living conditions (Ellis et al. 2016; White et al. 2016).

We analysed minute-by-minute PA data (sampling frequency: 30 Hz) using ActiLife software Version 6.13.6 (Actigraph LLC, Pensacola, FL, USA). Using the Choi non-wear algorithm (Choi et al. 2011), non-wear periods were defined as intervals of ≥ 90 min with zero activity counts, allowing for 2 consecutive interrupted minutes with counts below 100. Only participants with at least 4 monitoring days, each with a minimum of 10 h of wear time, were included as valid accelerometer data (Troiano et al. 2008). Minute-by-minute activity counts during valid wear time were categorised into four levels of PA intensity (sedentary, light, moderate and vigorous) using established cutpoints. These cutpoints align activity counts with specific energy expenditure values (Troiano et al. 2008).

Prior large cohort studies of older adults with knee OA and US adults showed that few individuals accumulated accelerometer-measured vigorous-intensity PA over a 7-day tracking period. As a result, it is recommended to combine moderate- and vigorous-intensity PA into a single MVPA metric (Dunlop et al. 2011; Schuna et al. 2013). We computed the total minutes of MVPA and light-intensity PA for three daily time blocks: morning (8 a.m.–12 p.m.), afternoon (12 p.m.–5 p.m.) and evening (5 p.m.–9 p.m.). To determine the average hourly MVPA minutes in each block, we divided the total MVPA minutes recorded in each block by the total hours in that block. We applied the same approach to determine the average hourly light-intensity PA minutes in each block.

2.6 | Statistical Analyses

We visualised the high-frequency knee pain intensity data by plotting the momentary knee pain ratings of the index knee (the more symptomatic knee) 4 times daily across 10 consecutive days (40 pain data points) for each participant. To visualise the relationship between PA and pain for each participant, we added the average hourly MVPA minutes for each of the 3 daily time blocks alongside these pain ratings over the same 10-day period. Similarly, we added the average hourly light-intensity PA minutes for each time block to examine its relationship with pain.

Figure 2a illustrates the analytic approach for assessing the within-day temporal associations of PA minutes with subsequent momentary knee pain intensity. In the linear mixed-effects model, each observation consisted of a temporal pair of variables repeatedly measured over 10 days: average hourly PA minutes during a given time block (exposure variable) and the momentary pain rating reported at the end of the same time block (outcome variable). This model incorporated fixed effects for 4 variables: the average hourly MVPA minutes during a given time block, the average hourly light-intensity PA minutes during a given time block, the specific time block, and the day. Participant variability was accounted for as a random effect. Additionally, we adjusted for age, sex and BMI as fixed effects in the model. The null hypothesis was that average hourly MVPA, or light-intensity PA minutes, during a given time block are not associated with the subsequent momentary pain rating reported at the end of the same time block.

Figure 2b illustrates the analytic approach for assessing the between-day temporal associations of current-day PA minutes with next-day knee pain intensity. In the linear mixed-effects model, each observation consisted of a temporal pair of variables repeatedly measured over 10 days: total PA minutes during the current day (exposure variable) and the average pain rating during the following day (outcome variable). This model incorporated fixed effects of 3 variables: current-day total MVPA minutes, current-day total light-intensity PA minutes, and the day. Participant variability was accounted for as a random effect. Additionally, we adjusted for age, sex and BMI as fixed effects in the model. The null hypothesis was that total MVPA or light-intensity PA minutes during the current day are not associated with the average pain rating during the next day.

We reported the effect estimates, along with their 95% confidence intervals (CIs), and *p*-values. Statistical significance was set at a *p*-value threshold of 0.05, and all analyses were conducted using R version 4.4.0.

3 | Results

3.1 | Study Participants

Figure 3 illustrates the derivation of the study sample. The final sample included up to 454 observations across 10 consecutive days from 17 participants with knee OA (mean age 64.4 [SD 6.9] years, BMI 27.0 [SD 4.1] kg/m^2, and 59% were women). Among the 17 participants, 12 had 10-day accelerometer recordings, 3 had 9-day, 1 had 7-day, and 1 had 4-day recordings, resulting in a total of 158 participant-days of valid accelerometer data (defined as ≥ 10 h of wear time per day). The average completion rate for momentary pain ratings via text messages was 91%, with 6 participants (35%) completing all 40 pain ratings. The characteristics of the sample are detailed in Table 1. These baseline features are representative of individuals with mild to moderate symptom severity and functional impairments, as commonly reported in clinical cohorts of knee OA (Roos 2024; Chang et al. 2021; Messier et al. 2021).

3.2 | Pain Intensity: Within-Participant Patterns

Figure 4 shows the pain intensity in the index knee (more symptomatic knee) for each of the 17 participants throughout each day over a 10-day period. Pain intensity was highly variable for some and relatively stable for others. On a 0-to-10 NPRS, the pain variance among participants ranged from 0.24 to 3.79, with a median of 1.74 and a mean of 1.64. Figure S1 shows the scaled average hourly MVPA minutes alongside the pain intensity ratings for each of the 17 participants throughout each day over 10 days. Figure S2 shows individual plots for light-intensity PA.

3.3 | Within-Day Temporal Associations of PA With Immediate Subsequent Pain

The analysis sample consisted of 454 temporal pairs of PA minutes accumulated during a given time block and subsequent pain ratings recorded at the end of the same block, representing 96% of the possible 474 within-day observations (3 temporal pairs per day from 158 participant-days), with only

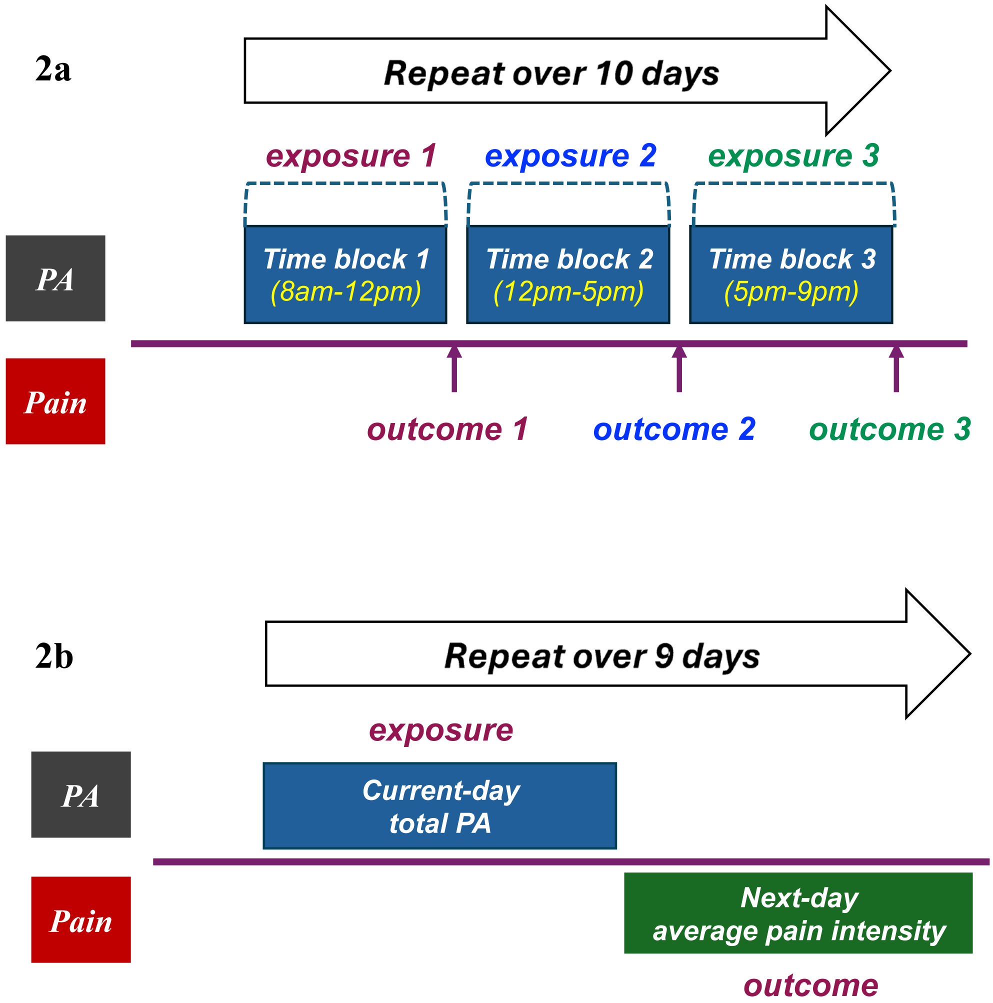

FIGURE 2 | Analytic approaches for assessing the temporal associations of PA minutes with subsequent knee pain intensity. (a) Analytic approach for assessing the within-day temporal associations of PA minutes with subsequent momentary knee pain intensity. Each observation consisted of a temporal pair of variables: average hourly PA minutes during a given time block (exposure) and momentary pain rating recorded at the end of the same time block (outcome). Each participant contributed up to 30 within-day temporal pairs over 10 tracking days. (b) Analytic approach for assessing the between-day temporal associations of PA minutes with subsequent pain intensity. Each observation consisted of a temporal pair of variables: total PA minutes during the current day (exposure) and average pain rating during the following day (outcome). Each participant contributed up to 9 between-day temporal pairs over 10 tracking days.

4% missing due to incomplete pain entries. Histograms and Q-Q plots indicated that MVPA was not normally distributed, so we log-transformed it for the linear mixed-effects models. Similarly, pain ratings had a skewed distribution with many zeros, so we applied a log transformation to (pain rating + 0.5) for the analysis (Baumgärtner et al. 2002; Lötsch et al. 2020; Mailloux et al. 2021). As shown in Table 2, higher MVPA minutes accumulated during a given time block were associated with greater subsequent knee pain recorded at the end of the same block, with an effect estimate of 0.108 (95% CI: 0.019, 0.197, $p = 0.018$) in the unadjusted model and 0.112 (95% CI: 0.023, 0.201, $p = 0.014$) in the adjusted model. For example, greater MVPA minutes accumulated during the time block of 8 am to 12 pm were associated with a higher knee pain reported at the end of the same block (e.g.,12 pm). Light-intensity PA minutes showed no association with subsequent knee pain (see Table 2). To explore the potential influence of analgesic use on our findings, we conducted an exploratory subgroup analysis among the 7 participants who reported using analgesics for knee pain, aching, or stiffness in the last month at our study baseline. Findings from this subgroup mirrored those observed in the overall sample.

3.4 | Between-Day Temporal Associations of Current-Day PA With Next-Day Pain

The analysis sample consisted of 141 temporal pairs of total PA minutes during the current day and average pain ratings during the following day, representing 92% of the possible 153 between-day observations (9 temporal pairs from 17 participants). Histograms and Q–Q plots showed that average daily pain ratings were not normally distributed and contained some zeros, so we applied a log transformation to (pain rating + 0.5) for the linear mixed-effects model. As shown in Table 3, There was no significant association of current-day MVPA minutes or light-intensity PA minutes with knee pain intensity on the following day.

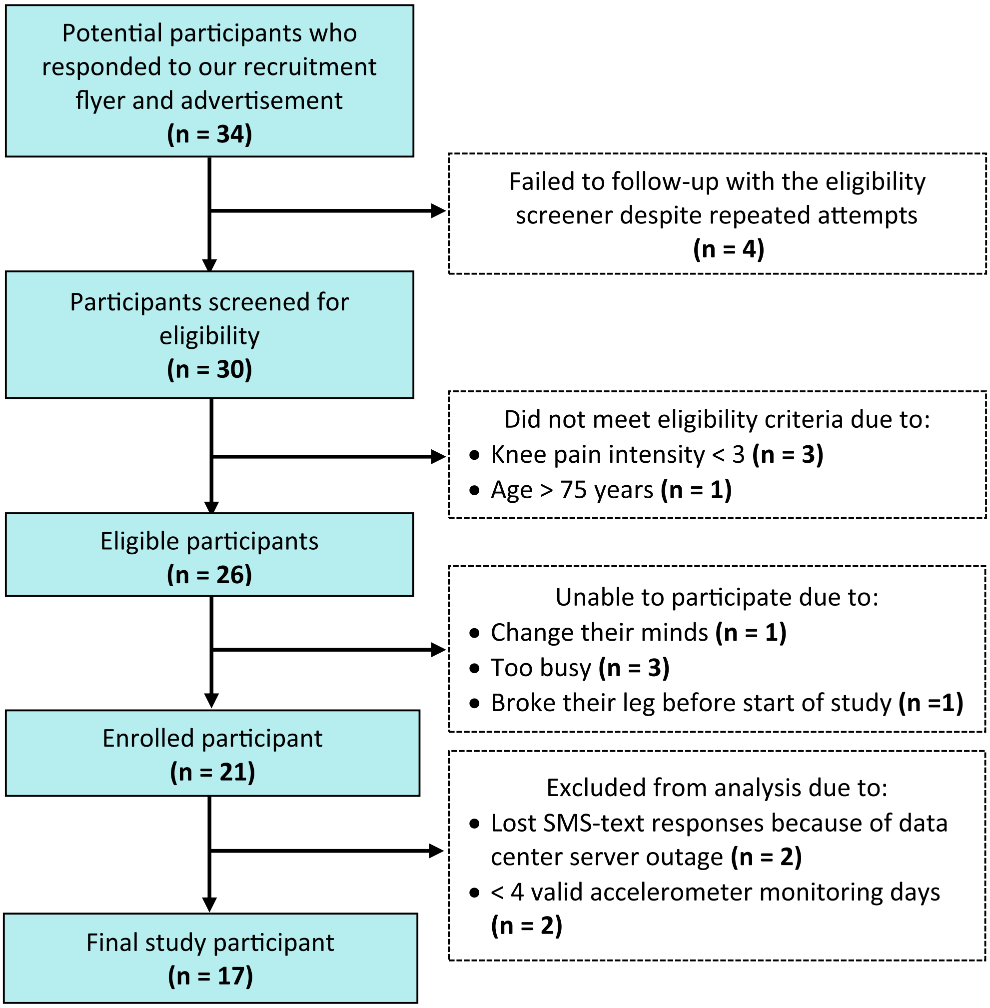

FIGURE 3 | Study sample derivation.

4 | Discussion

In this exploratory EMA study examining the temporal associations of PA intensity with subsequent knee pain in individuals with knee OA, greater MVPA minutes were associated with an immediate increase in subsequent knee pain within the same day, while light-intensity PA showed no significant relationship with pain. In contrast, neither current-day MVPA nor current-day light-intensity PA minutes were associated with next-day knee pain. These preliminary findings suggest that while MVPA may exacerbate knee pain in the immediate short term, it did not necessarily predict pain levels for the following day. This is the first explorative study investigating the distinct temporal associations of MVPA and light-intensity PA with subsequent pain in individuals with knee OA, based on high-frequency data.

4.1 | Light-Intensity PA and Knee Pain

Our findings suggest that engaging in light-intensity PA may help prevent momentary movement-evoked knee pain, potentially supporting sustained PA engagement in the setting of chronic knee symptoms. This is particularly relevant given that many older adults with chronic knee symptoms do not meet the MVPA guidelines (Chang et al. 2020).

There is growing evidence for the health benefits of light-intensity PA. Loprinzi (2017) identified a significant inverse relationship between light-intensity PA and all-cause mortality. Specifically, each 60-min increase in light-intensity PA was associated with a 16% reduction in the risk of all-cause mortality, independent of MVPA and other confounders. Other studies have demonstrated the independent benefits of light-intensity PA for extending life expectancy (Del Pozo Cruz et al. 2021), reducing cardiometabolic risks (LaMonte et al. 2017), improving mental health, and boosting self-rated physical health and wellbeing (Buman et al. 2010). In people with knee OA, replacing 60 min of sedentary time with light-intensity PA lowered the risk of developing functional limitations by 17% over a two-year period (White et al. 2017). They (White et al. 2017) suggested that light-intensity PA could be a feasible and beneficial option for preventing disability in those experiencing pain with higher-intensity activities. These collective findings support light-intensity PA as a practical option for health and functional maintenance. Clinicians may consider recommending light-intensity PA as a viable and effective alternative to MVPA or a combination of both, based on the patient's pain intensity and

TABLE 1 | Study sample characteristics (17 participants).

Baseline characteristics	Mean (SD)	*N* (%)
Age (year)	64.4 (6.9)	
Sex (Female)		10 (59%)
BMI (kg/m^2)	27.0 (4.1)	
Other chronic health conditions (yes)		12 (71%)
MSK pain in other body regions (yes)		10 (59%)
Pain medication use for knee symptoms (yes)		7 (41%)
Pittsburgh Sleep Quality Index (PSQI) (range: 0–21, higher is worse)	6.6 (3.5)	
Pain Catastrophizing Scale (PCS) (range: 0–52, higher is worse)	13.1 (9.5)	
Bilateral knee symptoms (yes)		11 (65%)
Study knee (right)		8 (47%)
Knee pain after 30-min walking (range: 0–10)	3.8 (2.2)	
Worst knee pain in last week (range: 0–10)	5.3 (1.2)	
Knee pain duration (years)	13.8 (14.5)	
Knee Injury and Osteoarthritis Outcome Score (KOOS) (range: 0–100, higher is better)		
Pain	72.2 (12.9)	
Symptoms	54.8 (14.4)	
ADL	82.6 (11.6)	
Sport and recreation function	44.7 (19.3)	
Knee-related QoL	46.0 (17.9)	

Abbreviations: ADL = Activity of Daily Living; KOOS = Knee Injury and Osteoarthritis Outcome Score; MSK = musculoskeletal; QoL = quality of life.

variability. On the other hand, those wishing and able to engage in MVPA might be reassured that MVPA-related pain exacerbation could be transient and resolve by the next day.

4.2 | Temporal Patterns of PA Intensity and Knee Pain: Insights and Clinical Implications From High-Frequency Data

Previous studies examining the relationship between PA and knee pain have largely relied on cross-sectional designs and step counts, limiting their ability to explore the immediate impact of PA intensity on pain. Song and colleagues found higher knee pain was cross-sectionally associated with reduced MVPA minutes, but not light-intensity PA minutes (Song et al. 2018). Analysing knee pain intensity and step counts, collected every 3 months for up to 3 years, Brisson and colleagues observed no cross-sectional association between average daily step counts and average pain levels (Brisson et al. 2020). Similarly, Vivekanantham and colleagues assessed knee pain (rated twice per day) and step counts over 90 days and reported no significant difference in average daily step counts between those with high versus low average pain intensity (Vivekanantham et al. 2023).

Our work expands the scope by collecting high-frequency data and focusing on MVPA and light-intensity PA instead of step counts. This approach offers insights into how different PA intensities may influence pain, potentially through differences in joint loading and corresponding pain responses. Higher-intensity activities like MVPA generally increase joint loading and articular tissue stress (Chang et al. 2019; Felson 2013; Hunt et al. 2020; Mündermann et al. 2004), which may trigger an immediate pain increase (Amin et al. 2004; Birmingham et al. 2019). In contrast, light-intensity PA likely produces lower joint loading and may be more suitable for managing movement-evoked pain. Tracking PA intensity and pain at frequent intervals reveals how specific activity intensities affect pain in real-time, offering actionable insights for designing tailored, intensity-based PA recommendations that align with individual pain responses. Integrating digital health tools that provide real-time data on PA, pain and other key factors can facilitate more precise and adaptive management strategies, allowing for timely adjustments based on patient feedback and pain patterns. This personalised approach will promote sustained PA and improve long-term outcomes.

4.3 | Strengths and Limitations

Our study has significant strengths. First, the use of EMA enabled the capture of real-time data on PA and pain, reducing recall biases and enhancing ecological validity. This approach has already yielded valuable insights into behaviour patterns and triggers in mental health and behavioural research (Burke et al. 2017; Shiffman et al. 2008), and it holds great potential

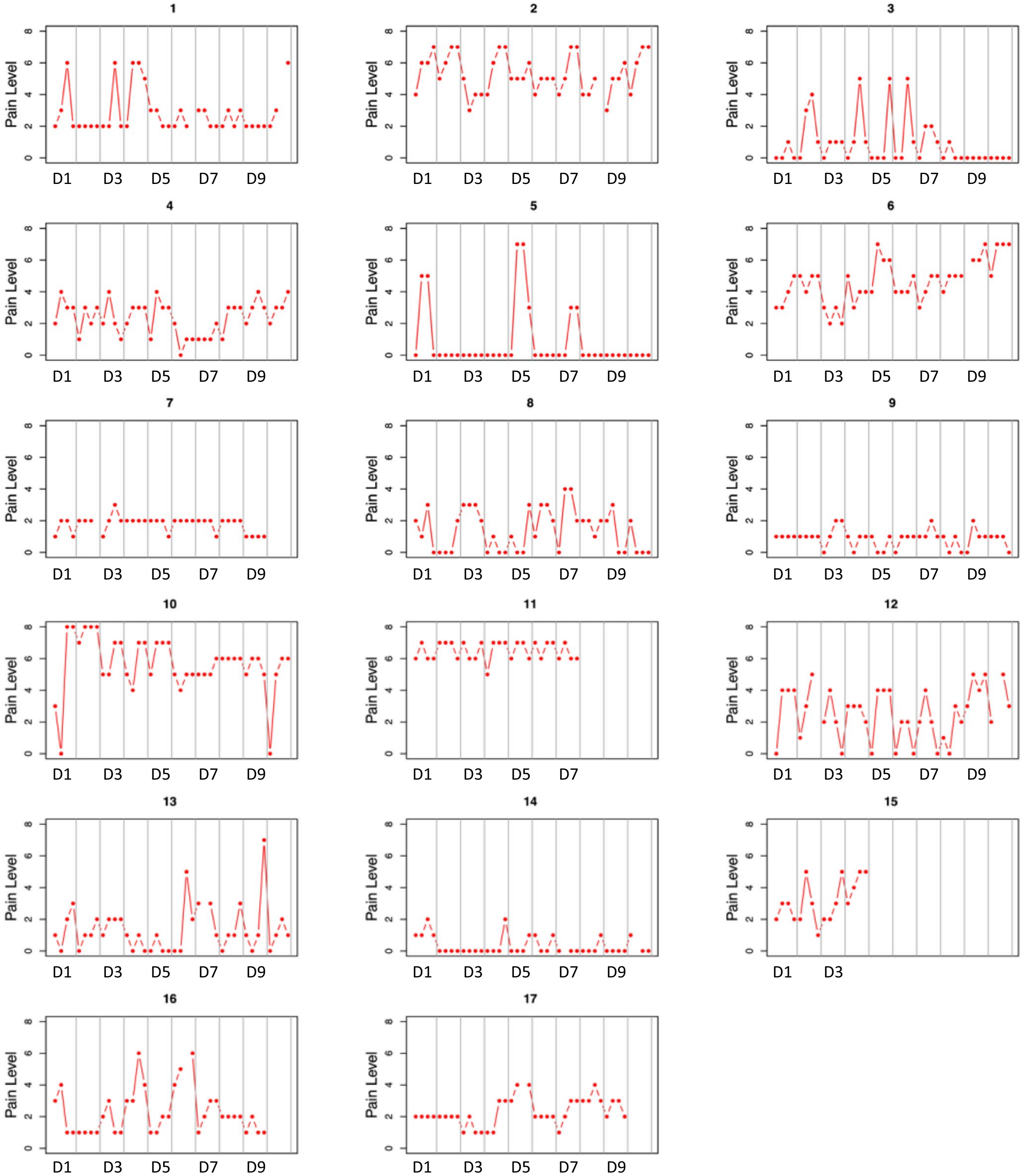

FIGURE 4 | Pain intensity over a 10-day period for each participant. The *x*-axis represents days (D1 to D10). The *y*-axis shows pain intensity ratings. Each day included 4 momentary pain ratings. For example, Participant 1's (upper left plot) pain level fluctuated between 2 and 6 with 1 missing data point on both Day 6 (D6) and Day 10 (D10).

for advancing research in PA and pain studies. The response rate for pain rating was 91% in the current study, comparable to other EMA studies with similar tracking periods (Martire et al. 2016; Overton et al. 2024). Second, the high-frequency data collected—pain ratings 4 times daily and minute-by-minute activity counts over 10 days—provided a granular view of the temporal dynamics between PA and pain, revealing patterns that might be missed with lower-frequency sampling. Lastly, by

TABLE 2 | Within-day temporal associations of physical activity level with subsequent knee pain intensity: effect estimates (95% CI) from linear mixed-effects models (454 observations).

Factor	Estimate	P-value
Base model[a]		
MVPA (minutes)	**0.108 (0.019, 0.197)**	**0.018**
Light-intensity PA (minutes)	−0.003 (−0.011, 0.005)	0.461
Time block[b]	0.058 (−0.014, 0.129)	0.115
Day[c]	−0.011 (−0.031, 0.008)	0.264
Adjusted Model (adjusting for age, sex and BMI)		
MVPA (minutes)	**0.112 (0.023, 0.201)**	**0.014**
Light-intensity PA (minutes)	−0.003 (−0.011, 0.005)	0.461
Time block[b]	0.059 (−0.012, 0.131)	0.108
Day[c]	−0.011 (−0.031, 0.009)	0.284
Age (year)	**0.066 (0.012, 0.121)**	**0.046**
Sex	−0.315 (−0.933, 0.302)	0.371
BMI (kg/m^2)	0.087 (−0.001, 0.175)	0.097

Note: Bold fonts indicate statistically significant odds ratio with associated 95% confidence interval that excludes 0.
Abbreviation: MVPA = moderate-to-vigorous intensity physical activity.
[a]Outcome = knee pain rating, fixed effects = MVPA, light-intensity PA, time block, and day; random effect = participant ID.
[b]Time block: 3 temporal pairs of time block and knee pain rating each day.
[c]Day: up to 10 days of temporal pairs of PA and pain data.

TABLE 3 | Between-day temporal associations of current-day physical activity level with next-day knee pain intensity: effect estimates (95% CI) from linear mixed-effects models (141 observations).

Factor	Estimate	*p*
Base model[a]		
Daily MVPA (minutes)	0.001 (−0.001, 0.002)	0.443
Daily light-intensity PA (minutes)	−0.001 (−0.002, 0.0003)	0.123
Day[b]	−0.005 (−0.031, 0.021)	0.732
Adjusted model (adjusting for age, sex and BMI)		
Daily MVPA (minutes)	0.001 (−0.001, 0.003)	0.353
Daily light-intensity PA (minutes)	−0.001 (−0.002, 0.0002)	0.128
Day[b]	−0.004 (−0.030, 0.022)	0.788
Age	**0.069 (0.014, 0.123)**	**0.039**
Sex	0.391 (−0.218, 0.999)	0.266
BMI (kg/m^2)	0.083 (−0.005, 0.171)	0.110

Note: Bold fonts indicate statistically significant odds ratio with associated 95% confidence interval that excludes 0.
Abbreviation: MVPA = moderate-to-vigorous intensity physical activity.
[a]Outcome = knee pain rating on the next day, fixed effects = current-day MVPA, current-day light-intensity PA, and day; random effect = participant ID.
[b]Day: up to 9 days of temporal pairs of PA and pain data.

distinguishing between MVPA and light-intensity PA, the current study explored the differential effects of these activity levels on knee pain.

Several limitations should be considered when evaluating the implications of this study. The small sample size may limit the generalisability of the results to the broader population of knee OA. However, the high-density data collected through EMA provided an extensive set of real-time data points, enabling robust analyses of the temporal relationship between PA and pain (Leroux et al. 2024). Future studies with larger samples could further confirm these preliminary findings. The study did not comprehensively explore other factors that may influence the PA-pain dynamics, such as psychological factors, social support or environmental conditions. While our use of within-participant modelling helped reduce between-participant variability and potential confounding, unmeasured factors may still have impacted the observed associations. For instance, we did not collect real-time data on the type, dosage, and timing of analgesic use, which could have provided additional context for interpreting pain intensity fluctuation. However, an exploratory subgroup analysis of the 7 participants who reported analgesic use at our study baseline yielded similar findings.

We applied accelerometry activity count cutpoints derived from waist-worn devices (Troiano et al. 2008) to classify PA intensity in wrist-worn data, which could potentially introduce misclassification. We adopted this pragmatic approach due to the absence of widely accepted, validated cutpoints for wrist-worn devices in older adults. Additionally, individual differences in physical fitness and movement patterns further complicate the validity of any single set of cutpoints across populations (Bammann et al. 2021; Nnamoko et al. 2021). Since our analysis focused on within-person temporal associations, this study design is less likely to introduce meaningful bias to our main findings.

Finally, we did not assess the relationship between step counts and pain like previous studies (Brisson et al. 2020; Vivekanantham et al. 2023). However, activity counts from the ActiGraph accelerometer provide a more reliable PA measure than relying on calculated step counts (Hyde et al. 2022; John et al. 2018; Toth et al. 2024). Unlike a basic pedometer, the ActiGraph employs a step-detection algorithm based on thresholding the band-pass filtered acceleration signal from the *y*-axis. The sensitivity of this algorithm varies with signal frequency, which can lead to under- or over-estimation of steps in certain conditions (John et al. 2018).

4.4 | Conclusions

In this exploratory EMA study of older adults with knee OA, greater accelerometer-measured MVPA minutes were temporally associated with a subsequent increase in knee pain within the same day, whereas light-intensity PA did not significantly affect pain levels. Neither current-day MVPA nor light-intensity PA minutes were associated with next-day knee pain. These preliminary results suggest that while MVPA may exacerbate knee pain in the short term, it does not influence pain levels the following day. Light-intensity PA may present a more tolerable alternative to MVPA, especially for those experiencing movement-evoked pain. These findings should be interpreted with caution due to the study's exploratory nature and small sample size. Nonetheless, they offer a valuable foundation for future work. Further larger-scale studies are needed to confirm these preliminary observations and to refine PA guidelines for individuals with knee OA.

Author Contributions

Alison H. Chang: conceptualisation, methodology, formal analysis, investigation, writing – original draft, writing – review and editing, visualisation, project administration. **Emma Hertel:** methodology, investigation, writing – review and editing. **Malene Kjær Bruun:** methodology, investigation, writing – review and editing. **Erika Maria Kristensen:** methodology, investigation, writing – review and editing. **Kristian Kjær-Staal Petersen:** conceptualisation, writing – review and editing, supervision. **Michael Skovdal Rathleff:** conceptualisation, methodology, writing – review and editing, supervision.

Acknowledgements

We sincerely thank all the study participants for their valuable time, effort and contribution to this work. Dr. Alison H. Chang had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Dr. Kristian Kjær-Staal Petersen acknowledges funding from the Center for Neuroplasticity and Pain (CNAP), supported by the Danish National Research Foundation (DNRF121), and the Center for Mathematical Modeling of Knee Osteoarthritis (MathKOA), funded by the Novo Nordisk Foundation (NNF21OC0065373).

Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.