Are objective measures of sleep and sedentary behaviours related to low back pain flares?

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Abstract

Risk factors for low back pain (LBP) flares have been considered about self-reported measures. This case–crossover study aimed to investigate whether (1) objective measures of physical activity and sleep were associated with the risk of experiencing LBP flares and (2) these associations differed for flares defined as pain 2 or more points greater than average pain over the period using an 11-point Numerical rating scale (0-no pain and 10-worst pain imaginable) (pain-defined flare: PDF) and flares identified by participants according to a broader definition that considered emotions or coping (self-reported flare [SRF]). We included 126 participants who had experienced LBP for >3 months. Physical activity and sleep were monitored for 28 days using wearable sensors. Occurrence of flares (PDF or SRF) was assessed daily using a smartphone application. Data on exposure to risk factors 1, 2, and 3 days preceding PDF or SRF were compared with nonflare control periods. Conditional logistic regression determined association between each factor and flares. Data show that day-to-day variation in physical activity and in-bed time are associated with the risk of LBP flares, but associations differ depending on how flare is defined. Longer in-bed time increased the risk of PDF but not SRF. Although physical activity was not associated with the risk of PDF, greater sedentary behaviour increased the risk of SRF

and being more physically active decreased the risk for SRF. These results highlight the potential role of targeting sleep and physical activity in interventions to prevent LBP flares and indicate that risk factors differ depending on how LBP flares are defined.

1. Introduction

Low back pain (LBP) is the leading cause of disability worldwide, and its burden is increasing.[14] A disproportionate share of costs related to productivity losses is due to fluctuations of LBP symptoms.[35,50] Exacerbations of LBP lead people to seek medical care and take time out of work. Meaningful exacerba- tions of symptoms are often referred to as LBP "flares."[4,38,54] Individuals who experience LBP flares report functional limitations, self-reported poor health, emotional changes, and de- pressive symptoms.[38,54] The flare experience also leads to higher rates of opioid use and physician visits. [4,45,54] Although risk factors for flares have been investigated in musculoskeletal conditions such as osteoarthritis and rheumatoid arthritis,[18,53,55] research has only begun to understand the risk factors for flares in LBP.[6,44]

An online survey revealed that individuals with LBP highlight a range of factors they consider to increase the risk for flare.[6] This work highlighted a bias to biomedical factors but some consideration of psychosocial features. Participants believed that they experienced flares mostly because of active movements and static postures. Other factors such as psychological state and sleep were also mentioned but infrequently. Of note, individuals with LBP do not consider that flare is the same as, and characterised only by, an increase in pain.[38]

Two recent studies have tested the validity of some of these triggers and considered whether they differ depending on how flare is defined. A small case–crossover study identified that stress, depressive symptoms, and prolonged sitting, but not engagement in physical activity, were associated with LBP flares defined by an increased in pain.[44] In a more recent study, participants reported pain (several times per day) and whether they had experienced a flare (self-reported flare [SRF]; according toa standardised definition that considered multiple domains[5,7]). This study identified that the risk of a 2-point

increase in pain was increased by higher pain levels in the previous afternoon and evening, fatigue, fear avoidance, engaging in physical activity, and very poor sleep. Yet in the same participants, risk of SRF was increased by subtle changes in sleep the preceding night and higher pain in the morning on the preceding day. This suggests that an increase in pain and SRF may not always be identical, and it is plausible that these 2 scenarios could have different risk factors. A problem with the previous studies is that all measures of predictor variables were self-reported, and it is possible that an individual's perception of activity and/or sleep may be influenced by features that affect perception of pain or perception of flare. For instance, mood affects the report of pain[46] and physical activity.[30] This can be further investigated by objective measures.

This study aimed to determine whether objective measures of physical activity and sleep are associated with increased risk of experiencing a LBP flare and risk factors were affected by how flare was defined (a pain increase or an individual's perception of whether they experienced a flare).

2. Methods

2.1. Participants

Participants were recruited by promotion through advertisements placed on university and community online noticeboards, advertisements in the local community, by contacting participants from previous studies of LBP and snowballing (ie, eligible and ineligible participants were encouraged to recommend the study to people they believe might be eligible). Inclusion criteria were (1) age between 18 and 50 years, (2) LBP (defined as pain and discomfort below the costal margin and above the inferior gluteal folds, with or without referred leg pain[9]) that had been present for at least 3 months, (3) access to a smartphone and internet, and (4) good understanding of spoken and written English, which was subjectively assessed by the recruiter and also based on the participants' ability to read and understand the study's advertisement and participant's information sheet. Individuals with a history of spinal surgery and/or a major disease or disorder other than LBP were excluded. Participants provided written informed consent, and the study was approved by the Institutional Medical Research Ethics Committee.

Participants also provided self-reported measures of sleep, physical, and psychological factors, which were considered in an earlier study of risk factors for flares.[7]

2.2. Baseline demographic data

At baseline, participants provided information regarding the duration of LBP symptoms, current pain intensity, age, sex, and comorbidities.

2.3. Activity monitoring

Participants wore 2 small (23.5 x 43 x 5 mm, 10 g) wearable sensors (triaxial accelerometer; activPAL3 micro, PAL Technologies, United Kingdom). Sensors were covered in waterproof coating and attached to the participants by the researcher (E.S.) using a hypoallergenic bandage (Tegaderm, 3M) or a fabric adhesive (Fixomull, BSN medical). One sensor was attached to the right thigh (on the midline, midway between the hip and the knee as per the manufacturer's manual), and a second sensor was attached to the trunk (over the lower rib cage[41]). Participants wore the sensor for 28 consecutive days, with replacement at 7- to 10-day interval because of battery life. Participants were instructed on how to remove and reattach the sensors and told that sensors could be removed if necessary. Participants were also advised to engage in their usual activities while wearing the sensors and to keep track of the times when the sensors were removed and reattached using a logbook embedded in a smartphone app.

Proprietary software (activPAL) was used to identify periods of upright (vertical), sedentary (horizontal) sensor positions and ambulatory activity from the thigh sensor. These periods were exported as events that indicate the start and end of each continuous period of time spent sedentary (ie, sitting or lying), standing (upright), or walking. Using custom programs written in MATLAB 2014b (The MathWorks, Natick, MA), periods unlikely to be part of waking hours were identified as *in-bed* or *nonwear* based on previously published algorithms.[2,52] Using this method, Winkler and colleagues[52] achieved near identical results for agreement with the diary-based method in the waking wear (yes or no) classifications of each second, with a high median sensitivity (0.95), specificity (0.99), and chance-corrected agreement as indicated by kappa (0.94).[52] *In-bed* periods were identified using a 2-step algorithm. In step 1, "long sedentary periods" (.5

hours) are identified, and in case none are found, the largest "short sedentary periods" (.2 hours) are selected. Then, step 2 searches within the time window of 15 minutes before or after the in-bed period for independent events that are more likely part of the same continuous in-bed period; in case it finds another sleep period or period in which the sensor is stationary of .2 hours, these are then assimilated into the in-bed period previously identified.[48] Periods of *nonwear* were identified if sensor data indicated a period of continuous stationary or standing events with a duration of .12 hours (which implies the sensor had been removed and was lying horizontal or vertical, respectively) or stationary or standing events of 71 hours duration that started during unlikely periods of the day: long sedentary periods starting between 8 AM and 6 PM or standing events starting between midnight and 6 AM.[2,47] Periods identified as *in-bed* that were unexpected, eg, when they occurred during the day (which could be the case for shift workers), were verified against the self-reported bed or wake times. All *nonwear* periods were checked against self-reported nonwear times where possible (ie, when the daily diary was completed). Waking hours were determined because the time was not classified as *in-bed* or *nonwear*. For each day, the amounts of time sedentary, standing, and walking were expressed as percentage of waking hours. Energy expenditure during waking hours was also calculated for each posture or activity by multiplying the metabolic equivalent (MET) value of each posture or activity (sleeping = 0.9 MET, sedentary = 1.25 MET, standing = 1.4 MET, and walking at a cadence of 120 steps per minute = 4 MET) by the duration of time in the posture or activity to obtain the energy expenditure in MET hours (MET-h). Energy expenditure during walking at step cadences other than 120 steps per minute was calculated using a linear approximation: Energy expenditure (MET-h) = [1.4 + (4 − 1.4) x (step cadence/120)] x activity duration.[33,52] Steps were extracted as events[52] from the activPAL software.

Furthermore, because the *in-bed* periods also included time in bed but not asleep,[41] the sleep times were also estimated using raw accelerometer data from both the thigh and trunk sensors. Raw acceleration signals from the trunk sensor were plotted, with the start and end time of *in-bed* periods indicated. These plots were visually inspected to identify the likely moments of *sleep onset* and *wake up* based on the reasoning that, when the participant is sleeping, the trunk should be in horizontal position and trunk movement is negligible for extended periods. On this basis, *sleep onset* was estimated by visual

inspection as the time when fluctuations in trunk acceleration stopped, which would indicate cessation of small movements that occur when awake, and wake up time was identified using the converse criteria. Figure 1 highlights the steps taken in the analysis. The following variables were calculated from the wearable sensor data:

(1) %Sedentary: total number of waking hours spent sedentary (thigh sensor horizontal), expressed as percentage of waking hours;

(2) %Standing: total time spent in standing (sensor vertical),expressed as percentage of waking hours;

(3) %Walking: total time spent walking, expressed as percent-age of waking hours;

(4) Total MET: total energy expenditure during waking hours calculated from the total amount of time spent sedentary, standing, and/or walking;

(5) %MET < 1.4: percentage of waking hours when the participant was sleeping, sedentary, or upright MET (MET < 1.4)[33,52];

(6) %MET 1.4 to 3: percentage of waking hours when the participant was slow walking with a cadence of up to 74 steps per minute (MET 1.4 to 3.0)[33,52];

(7) %MET 3 to 4: percentage of waking hours when the participant was normal to fast walking with a cadence up to 120 steps per minute (MET 3.0 to 4.0)[33,52];

(8) %MET > 4: percentage of waking hours when the participant was very fast walking or running with a cadence of greater than 120 steps per minute (MET > 4.0)[33,52];

(9) In-bed hours: total duration of *in-bed* periods, calculated as described above; and

(10) Sleep hours: estimated time that the participant was asleep, calculated as described above.

When considering the sleep measures (ie, in-bed hours and sleep hours) to exclude the possibility that a flare had begun during the night and interrupted sleep, we considered data for the sleep periods that preceded the day before the flare. That is, if the flare was reported or identified on Saturday, sleep measures were considered for Thursday night or Friday morning (1 day before), Wednesday (2 days before) night, and Tuesday (3 days before) night. Activity measures were expressed as a percentage of the waking hours

rather than absolute hours because these avoided differences related to variation in the duration of sleep and periods of nonwear.

2.4. Self-reported data

At baseline, participants downloaded the smartphone application (RealLife Exp, Life Data). For the 28 consecutive days of data collection with the activity sensors, participants were prompted at different times of the day to answer questions related to pain intensity, occurrence of SRFs, bed time, and wake up time. The variables and time points assessed were:

(1)   Pain intensity: reported using a numerical rating scale (NRS) from 0 (no pain) to 10 (worst pain imaginable). Participants received a notification to complete a brief survey (1) in the morning (at a random time between 6 and 10 AM), (2) at a random time between 12 and 6 PM, and (3) at 8 PM in the evening, with the instruction to complete the survey before going to bed. Of note, in the evening, participants were asked to rate their average pain score of the day.

(2)   Self-reported flares: Participants were prompted in the evening to identify whether they had experienced a flare by affirmative response to the question "Did you experience a flare of low back pain today?" with flare defined as "an increase in pain or other related symptoms that lasts from hours to weeks and is difficult to settle. You may also have mood changes and/or difficulty with your normal activity."

(3)   Self-reported bed time: Participants were prompted in the morning to indicate the date and time they went to bed; What time did you go to bed last night?

(4)   Wake-up time: Participants were prompted in the morning to indicate the date and time they woke up; What time did you wake up this morning?

2.5. Identification of case and control periods

Case and control periods (explained below) were automatically identified using custom programs written in MATLAB 2014b (The MathWorks). First, all days in which participants reported flares were identified (SRF; when participants answered "yes" to

the question described above). Second, we identified days with evening pain that was 2 or more points greater than average evening pain on days without SRF, which we refer to as pain-defined flares (PDFs). To operationalise the selection of PDFs, average pain was calculated as the mean of evening pain ratings over all days that were not identified as SRF to reflect the participant's pain level under "typical conditions," when they could have pain but did not consider they were experiencing a flare. Then, PDF was identified as any day when pain reported in the evening was 2 or more points higher than average pain on the NRS. The threshold of a 2-point increase over the patient's average pain score was selected because this value has been used in previous studies of flares for other musculoskeletal conditions[27] and has been identified as the minimal important change in pain.[31,42] It was expected that some or many flares would be identified as both a SRF and a PDF. As we aimed to identify whether features that occurred in the days preceding a flare increased the risk of a flare, only flares (SRFs and PDFs) that were preceded by at least 3 days without a flare (preflare) were considered. The *case period* was selected as 3 days before the SRF or PDF. If a flare occurred over multiple consecutive days, the case period was selected as the days preceding the first day of the flare. The *control period* was defined as 3 days that preceded a day without a SRF and PDF.

2.6. Statistical analysis

Conditional logistic regression was used to determine whether the odds that a day would be followed by a flare (ie, PDF or SRF) was associated with (1) %sedentary, (2) %standing, (3) %walking, (4) total MET, (5) % MET < 1.4, (6) %MET 1.4 to 3, (7) %MET 3 to 4, (8) %MET > 4, (9) in-bed hours, and (10) sleep hours. Only participants with both case (flare) and control periods were included in the analysis. Conditional logistic regression models estimate within-participant effects, where each participant acts as their own control; thus, time-invariant participant character- istics do not need to be adjusted for in these regression models.[34] For each flare definition, the exposure to each variable was independently assessed using 3 different case windows: 1, 2, and 3 days preceding a SRF or PDF.[43] These time windows were used because we wanted to investigate whether transient changes in physical activity and sleep were associated with the occurrence of LBP flares. Data were analysed by comparison of data from control

days with case days preceding a PDF or SRF. Odds ratios and 95% confidence intervals were calculated. Analysis was conducted in Stata version 15 (StataCorp, TX).

3. Results

A total of 460 participants were assessed for eligibility. Of those, 334 were excluded because they either declined to participate (153) or did not meet the inclusion criteria (181) (eg, 64 expected absences in the next 3 months, 57 did not expect to have pain for days or weeks over the next 3 months, and 4 did not have a smartphone with access to the internet). Among 126 participants recruited, 68.2% (86) had data for both case and control periods and thus had data available for analysis (8 withdrew, 5 had missing data, 1 participant had no days without flares, and the remaining 26 did not have case and control periods—ie, days that were preceded by at least 3 days without flare). With 86 participants experiencing both flare and control periods, there would be 80% power at the 5% level of significance to detect an OR of 3 for a flare if the probability of exposure among control periods was between 0.3 and 0.6 and the correlation coefficient for the exposure between matched case periods and control periods is not more than 0.25.

Sixty percent of the sample were women, and the mean (SD) age was 29 (9) years. Further details about the number of participants who experienced flare using each of these definitions, the number of days with flare and descriptions of the study sample are presented in Table 1. Detailed analysis of the relationship between PDF and SRF is described elsewhere.[8] The average number of missing values and the number of flares that were not preceded by 3 days without flare, and thus excluded from analysis, are presented in Supplemental digital contents 2 and 3, respectively (available at http://links.lww.com/PAIN/ B566).

3.1. Risk factors for pain-defined flare

Means (SD) of each potential risk factor for case (day with PDF) and control (before nonflare day) days are presented in Table 2. Longer in-bed hours (mean [SD]: case 8.0 (2.4) and control 7.4 [2.8]) increased the risk of a PDF 1 (OR 1.09, 95% CI 1.01-1.17) and 2 (OR 1.11, 95% CI 1.03-1.20) days later (Table 3). Sleep hours did not increase odds for PDF. OR approached 1 with narrow confidence intervals for associations between

%seden- tary behaviour (OR for different time intervals before PDF ranged from 1.00 to 1.01), %standing (OR ranged from 0.98 to 0.99), the different levels of estimated energy expenditure (MET) (OR ranged from 0.95 to 1.04), and the occurrence of a PDF (Table 3; analysis of activity data expressed in hours is presented in Supplemental digital content 1, available at http://links.lww.com/PAIN/B566).

3.2. Risk factors for self-reported flare

Means (SD) of each potential risk factor for case (day with SRF) and control (before nonflare day) days are presented in Table 4. Contrasting with PDF, greater %sedentary (sitting or lying) (OR 1.03, 95% CI 1.00-1.05) increased the odds of participants reporting a SRF the next day (Table 5), whereas higher % standing (OR 0.97, 95% CI 0.95-1.00) reduced the odds. Consistent with this observation, %MET < 1.4 (OR 1.03, 95% CI 1.00-1.05) and %MET 1.4 to 3 (OR 0.97, 95% 0.95-1.00) were associated with higher and lower odds of SRF on the following day, respectively. Similarly, higher total MET (OR 0.96, 95% CI 0.91-1.00) throughout the day was associated with a lower odds of experiencing a SRF 3 days later (Table 5).

4. Discussion

This is the first study that identified risk factors associated with the occurrence of LBP flares based on objective measures of physical activity and sleep. There were 3 novel observations. First, objective measures of physical activity and sleep provide evidence of different risk factors for flares defined by pain rating (NRS) that was ≥ 2 points greater than average (ie, PDF) and SRF. This concurs with data of self-reported measures.[7] Second, although sedentary behaviour did not increase the risk for a PDF, it was a risk factor for SRFs. The relationship between sedentary behaviour and SRF was substantiated by the contrasting observation of protective effects of greater physical activity. Third, longer in-bed hours, but not sleep hours, was associated with PDF. These observations support the notion that SRF is different from an increase in pain intensity and highlight potentially modifiable factors that could be targeted with intervention to reduce incidence of LBP flares.

Longer in-bed hours (approximately 30 minutes longer than in the days preceding a nonflare day) were associated with greater risk of PDF but with an OR close to 1 for SRF. This contrasts sleep hours, which did not increase the risk for flare. An earlier study of self-report sleep data in this cohort showed that low sleep *quality* was associated with the occurrence of LBP flares 1 and 2 days later, and high sleep rate (using a different measure) was associated with less likelihood of a LBP flare 1 day later.[7] Notably, this study did not find an association with self-reported sleep duration. This contrast between self-report measures and objective data has implications for previous work which has relied on self-report measures to investigate the impact of sleep duration,[10] but it is also critical to acknowledge that comparison with other data also require consideration of the period used for measurement—some studies consider the pain on the day that immediately followed on from the night evaluated for sleep[10] whereas we considered the night before that. When the findings of these studies are taken together, it might be concluded that the time in bed is not that same as sleep time (and that time in bed, while not asleep, is potentially counterproductive), sleep time might be relevant for the night immediately before the day with pain[10] (although it is difficult to confirm that the sleep duration was affected by pain), and the impact of sleep quality has impact over a latent period.[7]

The findings of this study concur with observations of Krause et al.,[26] which revealed that night-to-night changes in sleep quality, rather than sleep quantity, determined changes in pain sensitivity. This is pertinent when considered alongside the multidimensional nature of flares and the observation that changes in sleep architecture are known to be associated with pain,[11,40,51] affect,[13,15,17,49] and immunologic responses.[1,20,22,24,48] The observation that longer in-bed hours and poor sleep quality increased odds for flares can have several interpretations. First, longer in-bed hours may be a compensation for poor sleep quality. Second, it is plausible that the negative consequence of longer in-bed hours might be related to longer periods in sustained postures during bed time, which might be provocative for LBP.[16] Third, some participants may use sleep as a self-management strategy[37] and may stay longer in bed aiming to sleep longer to escape from pain. Fourth, given that these data imply that sleeping longer did not offset the effects of poor sleep and was associated with increased risk of flare, it is reasonable to speculate that interventions should target sleep quality as a priority.

We found that physical activity and sedentary time did not increase the risk of a day with increased pain. This differs slightly from observations of Suri et al.[44] that sitting (.6 hours) was a risk factor for a flare defined by an increase in pain. This difference might be explained by different definition of pain (Suri et al. asked participants to indicate "worsening of symptoms that lasted longer than 2 hours") or the patient group (Suri et al. Studied participants with LBP for ,3 months, whereas we included participants with LBP for at least 3 months, and risk factors for flare might differ with duration of LBP).

Notably, our data showed that greater sedentary behaviour (greater time sitting and lying, less time standing, and/or walking) increased the risk of a participant reporting a flare the next day, whereas standing and gentle physical activity reduced the risk. This has important implications. Although individuals who experience LBP argue that engaging in physical activity can trigger their LBP flares,[6] our findings indicate that sedentary behaviour was a risk factor, whereas being active was pro- tective. In addition, although a person's perception of exposure to moderate and vigorous physical activity has been suggested to increase the risk of a new episode of LBP,[43] our objective data suggest that activity is unlikely to cause patients to experience a flare. However, it is not clear how our objective measure of activity relates to a person's perception of the vigour of their activity. Regardless, our data support the notion that rest has negative impact on back pain[28,36] ould not "take back pain lying down," as advocated in public health campaigns.[3] Although participant's self-reported data have shown that high leisure time physical activity is a risk factor for a pain rating (NRS) that was $\geq$ 2 points greater than average (ie, PDF),[7] objective data did not confirm such association. This divergence could have 2 potential interpretations. First, physical activity in this analysis was estimated by METs based on the amount of time spent in specific postures (ie, lying, sitting, standing, or walking) and did not account for physical activity that involved body movements without ambulation (eg, playing golf or lifting weights at the gym), which may have been reported as leisure time physical activity in the earlier analysis. Further, our analysis did not consider specific movements that have been highlighted as triggers for back pain episodes (eg, heavy lifting) and could not discriminate vigorous physical activity (METs above 6) from moderate physical activity (METs 4-6).

4.1. Study strengths and limitations

Strengths of this study include a large sample, the use of a longitudinal case–crossover design, and objective data from wearable sensors. There are also limitations. First, measures derived from the sensors provide overall estimates of physical activity based on body posture but do not consider physical activity that did not involve ambulation and could not identify how physical activity was performed. Second, sleep was estimated from movements detected by the sensors. These data require further validation as a measure of sleep duration and cannot provide information about sleep quality. Third, our sample was selected based on broad criteria for LBP and did not consider whether risk factors for LBP flares differ between specific groups. Fourth, because we did not ask participants when (time of day) a flare started, we were unable to investigated risk factors that occurred with short latency on the day of the flare. Fifth, we did not take into consideration the days of the week when selecting case and control periods. It is possible that this might have influenced the results because sleep and physical activity patterns vary according to specific days of the week. Sixth, the sample was relatively young (mean = 29 years and range 18-50 years), with limited generalizability to the broader populations of patients with LBP. Seventh, we did not quantify latency to fall asleep or wake up because this is better identified using electroencephalography nor did we collect information regarding habitual sleep patterns and/or insomnia severity. Both measures should be considered for future work. Finally, it is important to consider that the definition of SRF included reference to activity, which could possibly influence the association between these variables. Although the reference to the impact on activity in the definition of flare might influence the participants' decision, this was an intentional decision based on the consensus opinions of experts and individuals with LBP.[5] This definition is aligned with the key note regarding the recently updated definition of pain that states "*Pain is always a personal experience that is influenced to varying degrees by biological, psychological, and social factors.*"[23]

4.2. Implications and future research

This study provides insight into the relationship between flare, physical activity, and sleep but cannot comment on the mechanisms underlying this relationship. Future studies are

needed to investigate how physiological, psychosocial, and biomechanical factors might interact to cause fluctuations in LBP that are meaningful to individuals with LBP. Longitudinal studies might be needed to assess dynamic changes in sleep architec- ture and transient flares.[12] Furthermore, the potential interaction between how much people move (quantity) and how they move (quality) requires consideration.

It is widely recognised that both sleep[25,29,32] and sedentary behaviour[19,21,39] influence long-term outcomes in LBP. This study adds to the existing literature by revealing that day-to-day variation in sleep behaviour (ie, in-bed hours) and physical activity affect LBP flare, highlighting the importance of both factors for short-term outcomes. These findings support the assumption that physical activity and sleep in interventions could prevent LBP fluctuations[7] but causality cannot be assumed. Potential efficacy of any intervention cannot be assumed on the basis of these associations and requires consideration in controlled studies.

5. Conclusion

Objective measures of physical activity and sleep revealed that risk factors for PDF differ from those for SRF. Longer in-bed hours and greater sedentary behaviour increased the risk of PDF but not SRF. Greater sedentary behaviour increased the risk of SRF, whereas being more physically active was protective. These findings highlight the potential role of targeting these factors in interventions to prevent LBP flares and indicate that risk factors for flare differ depending on whether this is identified according to a person's perception of having had a LBP flare, as we have defined it, or as an increase in pain.

Conflict of interest statement

The authors have no conflicts of interest to declare.

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Appendix A. Supplemental digital content

Supplemental digital content associated with this article can be found online at http://links.lww.com/PAIN/B566.

Supplemental video content

A video abstract associated with this article can be found at http:// links.lww.com/PAIN/B567.

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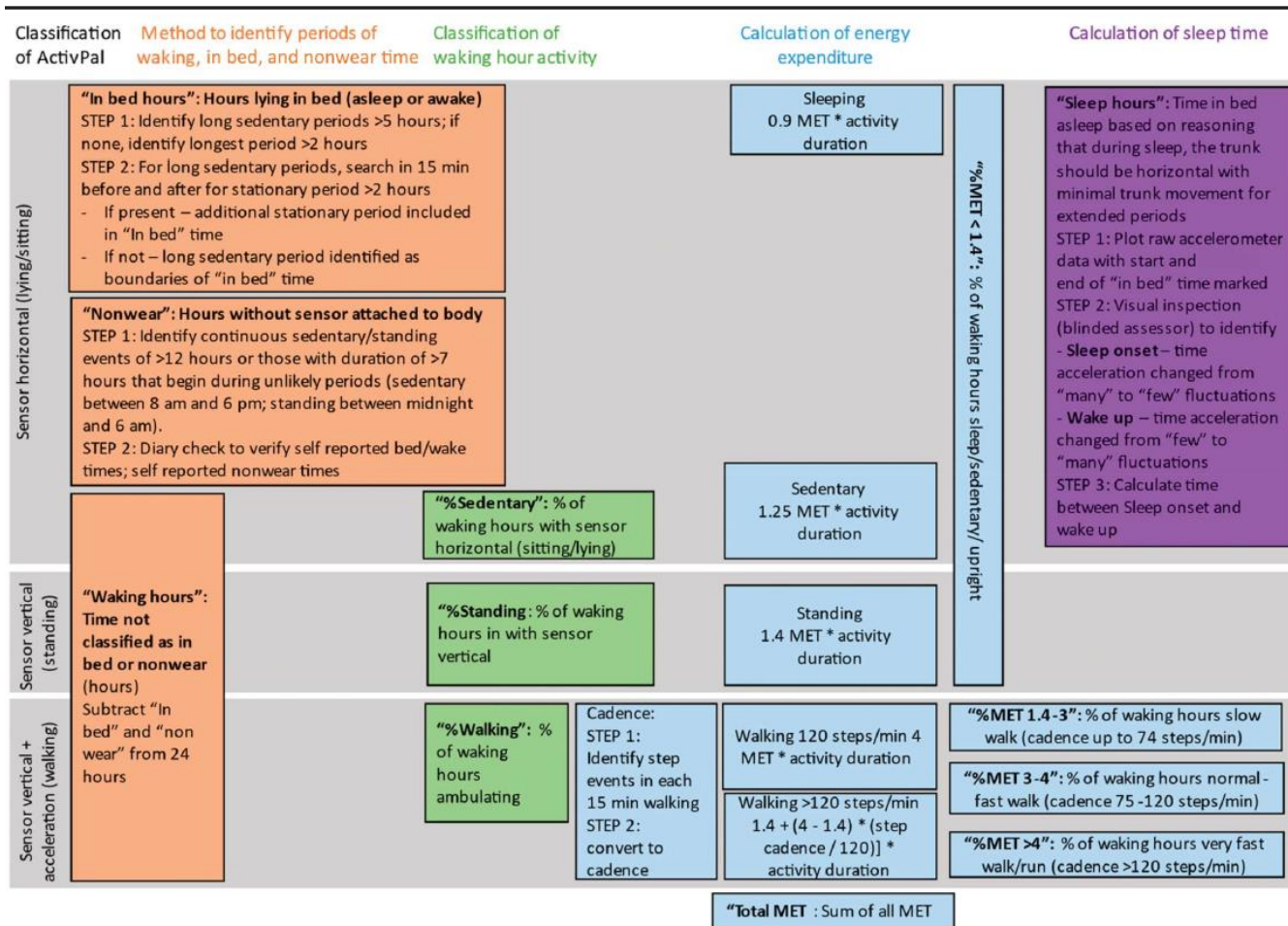
Figure 1. Detailed steps taken in the analysis. MET, metabolic equivalent for task.

Table 1. Frequency of flare type, average pain rating by flare type, and descriptors of study sample.

Flare types	SRF	PDF	SRF+PDF
No. of participants who experienced each flare type—n*	62	69	25
No. of flare days per participant—mean (SD) (range)†	6.7 (5.0) (0-22)	3.9 (3.5) (0-14)	2.4 (2.6) (0-11)
No. of days per flare—mean (SD)†	1.4 (0.7)	1.5 (0.5)	
No. of days between flares—mean (SD)†	3.8 (3.2)	5.7 (6.6)	
Average pain rating (NRS)—mean (SD)	4.4 (1.9)	5.7 (1.6)	5.5 (1.6)
Sex—n (%)			
Female (n = 52)	40 (76.9)	43 (82.6)	18 (34.6)
Male (n = 34)	22 (64.7)	26 (76.4)	7 (20.5)
LBP duration—n (%)			
10 weeks to 1 year (n = 23)	16 (69.5)	20 (86.9)	7 (30.4)
1 to 5 years (n = 27)	20 (74.0)	23 (85.1)	7 (25.9)
> 5 years (n = 36)	26 (72.2)	26 (72.2)	11 (30.5)

* Note that each participant may have experienced 1, 2, or all of the flare types.

† This includes all flares, but only those preceded by 3 days without flare are included in the analysis. LBP, low back pain; NRS, numerical rating scale; PDF, pain-defined flare; SRF, self-reported flare.

Table 2. Means and standard deviations of the potential risk factors in control days and in the days preceding pain-defined flares.

Risk factors	1 day before PDF		2 days before PDF		3 days before PDF	
	Mean (SD) control	Mean (SD) case	Mean (SD) control	Mean (SD) case	Mean (SD) control	Mean (SD) case
Sensors data						
%Sedentary	63.8 (15.1)	65.9 (12.5)	63.6 (15.3)	65.1 (13.1)	63.6 (15.3)	64.2 (15.0)
%Standing	24.7 (12.5)	23.3 (9.7)	24.8 (12.7)	23.6 (10.3)	24.8 (12.7)	22.8 (11.2)
%Walking	10.6 (5.0)	10.8 (5.0)	10.6 (5.2)	10.6 (5.2)	10.6 (5.2)	9.8 (5.2)
Total MET	23.8 (6.2)	23.6 (5.1)	23.8 (6.2)	24.4 (4.7)	23.8 (6.2)	24.0 (5.3)
%MET < 1.4	63.7 (14.8)	65.6 (12.4)	63.6 (15.0)	65.0 (12.7)	63.7 (15.0)	65.9 (13.6)
%MET 1.4-3	29.4 (13.7)	27.4 (11.1)	29.6 (13.7)	28.0 (11.2)	29.4 (13.7)	27.6 (12.0)
%MET 3-4	4.7 (2.8)	4.7 (2.6)	4.8 (2.8)	4.7 (2.7)	4.8 (2.8)	4.5 (2.5)
%MET > 4	2.1 (2.0)	2.3 (1.9)	2.1 (2.3)	2.3 (2.0)	2.1 (2.3)	2.1 (2.1)
In-bed hours	7.4 (2.8)	8.0 (2.4)	7.4 (2.8)	8.1 (2.3)	7.4 (2.8)	7.3 (3.1)
Sleep hours	8.0 (1.7)	8.0 (1.8)	8.0 (1.7)	8.1 (2.2)	8.0 (1.7)	8.0 (1.8)
Self-report						
Bed time	23.4 (1.8)	23.4 (2.1)	23.4 (1.8)	23.2 (2.0)	23.4 (1.8)	7.6 (2.3)
Wake time	7.4 (1.9)	7.4 (2.3)	7.4 (1.9)	7.2 (2.1)	7.4 (1.9)	8.0 (1.8)

Bed time, time participants went to bed; MET, metabolic equivalent for task; PDF, pain-defined flare; Wake time, time participants woke up.

Table 3. Association between objective and self-reported measures of sleep and physical activity and odds of a pain-defined flare starting 1, 2, and 3 days later.

Risk factor	1 day before PDF		2 days before PDF		3 days before PDF	
	OR control vs Pre	*P*	OR control vs Pre	*P*	OR control vs Pre	*P*
Sensors data						
%Sedentary	1.01 (1.00-1.03)	0.12	1.01 (0.99-1.02)	0.32	1.00 (0.99-1.01)	0.91
%Standing	0.99 (0.97-1.00)	0.16	0.99 (0.97-1.01)	0.25	0.98 (0.97-1.00)	0.063
%Walking	1.03 (0.99-1.07)	0.20	1.02 (0.98-1.06)	0.42	0.98 (0.93-1.02)	0.28
Total MET	1.00 (0.97-1.03)	0.93	1.03 (0.99-1.06)	0.16	1.01 (0.98-1.04)	0.58
%MET < 1.4	1.01 (1.00-1.02)	0.19	1.01 (0.99-1.02)	0.35	1.01 (1.00-1.03)	0.16
%MET 1.4-3	0.99 (0.97-1.00)	0.11	0.99 (0.98-1.01)	0.26	0.99 (0.97-1.01)	0.19
%MET 3-4	1.02 (0.95-1.11)	0.54	1.01 (0.93-1.10)	0.81	0.98 (0.90-1.06)	0.59
%MET > 4	1.04 (0.93-1.17)	0.50	1.03 (0.94-1.12)	0.57	0.95 (0.84-1.08)	0.47
In-bed hours	1.09 (1.01-1.17)	**0.03**	1.11 (1.03-1.20)	**0.006**	0.98 (0.92-1.05)	0.59
Sleep hours	0.95 (0.84-1.07)	0.39	0.96 (0.84-1.08)	0.46	0.93 (0.83-1.06)	0.29
Self-report						
Bed time	1.01 (0.90-1.13)	0.85	0.98 (0.88-1.10)	0.73	1.04 (0.92-1.16)	0.55
Wake time	0.91 (0.80-1.04)	0.19	0.88 (0.76-1.01)	0.066	1.01 (0.89-1.15)	0.83

Bed time, time participants went to bed; MET, metabolic equivalent for task; OR, odds ratio; pain-defined flare Wake time, time participants woke up; Bold—$P < 0.05$.

Table 4. Means and standard deviations of the potential risk factors in control days and in the days preceding self-defined flares.

Risk factors	1 day before SRF		2 days before SRF		3 days before SRF	
	Mean (SD) control	Mean (SD) case	Mean (SD) control	Mean (SD) case	Mean (SD) control	Mean (SD) case
Sensors data						
%Sedentary	64.5 (15.4)	66.2 (13.1)	64.5 (15.4)	62.2 (16.8)	64.5 (15.4)	62.9 (15.5)
%Standing	24.6 (12.9)	23.3 (9.8)	24.6 (12.9)	27.0 (13.3)	24.6 (12.9)	24.0 (11.7)
%Walking	10.5 (5.5)	10.5 (5.9)	10.5 (5.5)	10.9 (6.1)	10.5 (5.6)	11.0 (5.9)
Total MET	24.1 (5.4)	23.9 (4.2)	24.1 (5.4)	23.5 (5.0)	24.1 (5.4)	23.1 (6.3)
%MET <1.4	64.2 (15.3)	65.9 (13.0)	64.2 (15.3)	62.0 (16.6)	64.2 (15.3)	63.9 (15.0)
%MET 1.4-3	29.0 (13.9)	27.3 (11.2)	29.0 (13.9)	31.3 (14.6)	29.0 (13.9)	29.1 (12.9)
%MET 3-4	4.6 (2.5)	4.5 (2.7)	4.6 (2.5)	4.6 (2.8)	4.6 (2.5)	4.8 (2.7)
%MET > 4	2.2 (2.5)	2.2 (2.3)	2.2 (2.5)	2.1 (1.7)	2.2 (2.5)	2.3 (2.5)
In-bed hours	7.6 (2.6)	8.3 (2.1)	7.6 (2.6)	8.0 (2.2)	7.6 (2.6)	7.3 (2.7)
Sleep hours	8.1 (1.7)	8.1 (1.6)	8.1 (1.7)	8.1 (2.0)	8.2 (1.7)	8.4 (1.9)
Self-report						
Bed time	23.1 (1.6)	23.0 (1.6)	23.1 (1.6)	23.0 (1.7)	23.1 (1.6)	22.9 (1.7)
Wake time	7.2 (1.8)	7.1 (1.8)	7.3 (1.8)	7.1 (1.7)	7.3 (1.9)	7.3 (1.5)

Bed time, time participants went to bed; MET, metabolic equivalent for task; Wake time – time participants woke up; SD, standard deviation; SRF, self-reported flare.

Table 5. Association between objective and self-reported measures of sleep and physical activity and odds of a self-reported flare starting 1, 2, and 3 days later.

Risk factor	1 day before SRF		2 days before SRF		3 days before SRF	
	OR control vs Pre	*P*	OR control vs Pre	*P*	OR control vs Pre	*P*
Sensors data						
Sedentary (%)	1.03 (1.00-1.05)	**0.017**	0.99 (0.97-1.01)	0.41	1.00 (0.98-1.02)	0.75
Standing (%)	0.97 (0.95-1.00)	**0.038**	1.02 (0.99-1.04)	0.16	0.98 (0.96-1.01)	0.21
Walking (%)	0.97 (0.92-1.02)	0.24	0.99 (0.94-1.04)	0.63	1.00 (0.95-1.05)	0.94
Total MET	0.98 (0.93-1.03)	0.49	0.96 (0.91-1.01)	0.12	0.96 (0.91-1.00)	**0.043**
%MET < 1.4	1.03 (1.00-1.05)	**0.016**	0.99 (0.98-1.01)	0.46	1.01 (0.99-1.03)	0.49
%MET 1.4-3	0.97 (0.95-1.00)	**0.023**	1.01 (0.99-1.03)	0.23	0.99 (0.97-1.01)	0.50
%MET 3-4	0.92 (0.82-1.02)	0.12	0.93 (0.83-1.04)	0.18	0.99 (0.89-1.10)	0.83
%MET > 4	0.98 (0.86-1.11)	0.73	0.94 (0.81-1.10)	0.45	0.99 (0.88-1.11)	0.84
In-bed hours	1.12 (1.00-1.26)	0.053	1.05 (0.94-1.17)	0.39	0.91 (0.83-1.01)	0.07
Sleep hours	0.99 (0.84-1.17)	0.92	1.05 (0.89-1.23)	0.59	1.15 (0.99-1.34)	0.06
Self-report						
Bed time	1.00 (0.83-1.21)	0.96	0.97 (0.81-1.16)	0.72	0.90 (0.75-1.07)	0.24
Wake-up time	0.98 (0.82-1.17)	0.82	1.01 (0.85-1.19)	0.94	1.07 (0.91-1.26)	0.41

Bold—P < 0.05.

Bed time, time that participants reported they went to bed; MET, metabolic equivalent for task; OR, odds ratio; SRF, self-reported flare; Wake-up time, time that participants reported they woke up.