Initial Experiences with Longitudinal Self-Tracking of Sleep and Low Back Pain

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Abstract

Low Back Pain (LBP) is a leading cause of disability globally, making it a serious public health concern. In this paper we present the initial results and analysis of a longitudinal self-tracking study on sleep and LBP using a custom built mobile application. We designed and deployed a mobile app for a period of 7 months to collect daily and monthly sleep and low back pain data using custom and standardized questionnaires. We discuss the feasibility of our approach for longitudinal data collection. Our data analysis reveals heterogeneity in user perceptions of factors that affect their sleep and LBP. Combining our quantitative and qualitative analyses, we contribute to literature on sleep and LBP.

Keywords

Low Back Pain (LBP), Sleep, Longitudinal study, Self-tracking

1. Introduction

The global population of people aged 60 and above has been growing steadily. Aided by advances in technology, healthcare delivery and the medical field, the average life expectancy seems to be increasing. The longer people live, the more susceptible they become to conditions such as Low Back Pain (LBP) [1]. Thus, LBP has become a central concern in the public health domain [2]. The economic effect of LBP on individuals, families, and the society at large is high, with societal costs estimated to be 1% to 2% of the gross national product in Western countries, with a vast majority of these costs caused by disability and loss of work productivity [3, 4, 5].

Sleep is a vital biological function essential for the overall health of mammalian organisms [6] and allows for psychological recuperation and memory consolidation [5, 7]. In the same vein, poor sleep poses a potent risk factor for a number of physical and psychological ailments including obesity, dementia, diabetes, and chronic pain [8, 9, 5, 10]. Poor sleep quality is common among people suffering from chronic or acute pain such as LBP [5].

We conducted a long term study that offered daily observations from the perspectives of people living with LBP to investigate the effects of LBP on sleep: how does back pain affect one's sleep quality? In this vein, we also consider how factors such as time of sleep, wake up time, and sleep interruptions among others affect the perceived sleep quality and/or felt pain intensity of people living with LBP.

We present an exploratory study where we used a custom-built mobile application "Sleep Better with Back Pain" to investigate if, and in what ways, the felt pain affects the quality of sleep among people living with LBP. Our main contributions are:

1. A contribution to the literature on sleep and LBP, by investigating the relationship between LBP and sleep.
2. An initial prototype of a mobile application to collect massive amount of subjective data on sleep and LBP.
3. A feasibility study that highlights important contextual aspects that must be considered in future deployments.
4. We discuss how factors such as sleep time, wake up time, sleep disruptions, and pain intensity at night impact the felt restfulness of participants.
5. Factors leading to poor sleep among people living with LBP is heterogeneous and not only due to pain.

The results from our study are also encouraging concerning the number of completed daily surveys about sleep and LBP for several months, which is promising considering our future deployment of the next version of the application.

2. Related Work

2.1. Low Back Pain

Low Back Pain (LBP) adversely affects the quality of life of people [11] and produces annual global costs exceeding $100 billion [12]. Although there are numerous pain conditions, back pain carries the greatest societal burden, affecting nearly every adult at least once in their lifetime

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[12]. The Global Burden of Disease (GBD) study estimated that among 306 conditions, LBP ranked highest as the most significant condition with respect to the number of years lived with disability [13, 1].

2.2. Sleep

Recent studies have reported that sleep difficulties such as initiating and maintaining sleep, as well as experiencing inadequate sleep, can affect 20-30% of the western population on a daily to weekly basis [5, 14]. Sleep loss has been reported to impair cognition, psychomotor function, decision making, and immune function [15]. Poor sleep quality has also been considered to be a significant risk factor for people suffering with diseases such as diabetes, dementia, depression, obesity, pain, among others [16, 9]. The physical and psychological changes associated with poor sleep can significantly affect the quality of life and overall well-being of people [17]. Inadequate sleep also negatively impacts productivity and leads to substantial financial and non-financial costs, ultimately becoming an important social and economic burden [18].

2.3. The Relation Between Sleep and Pain

The exact mechanisms underpinning the sleep and pain relationship are unclear but likely to involve multiple contributors [19], such as depression [20], and daytime napping [21]. The comorbidities between chronic pain and sleep impairments have been shown in various studies [5, 22]. Similarly, studies suggest that the management of sleep may consequently improve co-morbid diseases [23, 24]. The interaction between sleep and pain is complex and challenging to understand [25]. A study by Mathias et al. [19] established that adult patients with chronic pain had worse measures for sleep onset latency and efficiency, recurrent awakenings, and time awake after sleep onset and exhibited worse scores on sleep measures such as total sleep time and light sleep duration, among others.

3. The "Sleep Better with Back Pain" app

We designed a cross-platform mobile application to collect periodical questionnaire data. The application was built with Flutter[1] and runs on both Android and iOS mobile operating systems. Flutter is a cross-platform mobile application development framework that makes it easy to build apps for the Android and iOS mobile operating systems using the same code base.

[1] https://flutter.com

3.1. On-boarding and Daily Use

The setup of the app was designed to be simple for the users. It has a welcome screen (Fig. 1a) that on-boards users by asking preliminary questions about user demographics and past experience with pain. This welcome screen also displays a consent checkbox which the user must agree to in order to proceed. A consent statement is provided beside the checkbox and contains links to the "user agreement" and "privacy policy" screens. After a successful on-boarding, the home screen (Fig. 1b) that displays daily surveys to be taken by the user is presented. Clicking on a list item opens up a detailed view with a list of survey questions (Fig. 1d). After successfully answering and submitting the answers to a survey, the completed survey is removed from the list depending on whether it is a daily or monthly survey. Monthly surveys are removed from the list for the given month once answered. Daily surveys on the other hand are removed for the given day only, and are displayed again the next day.

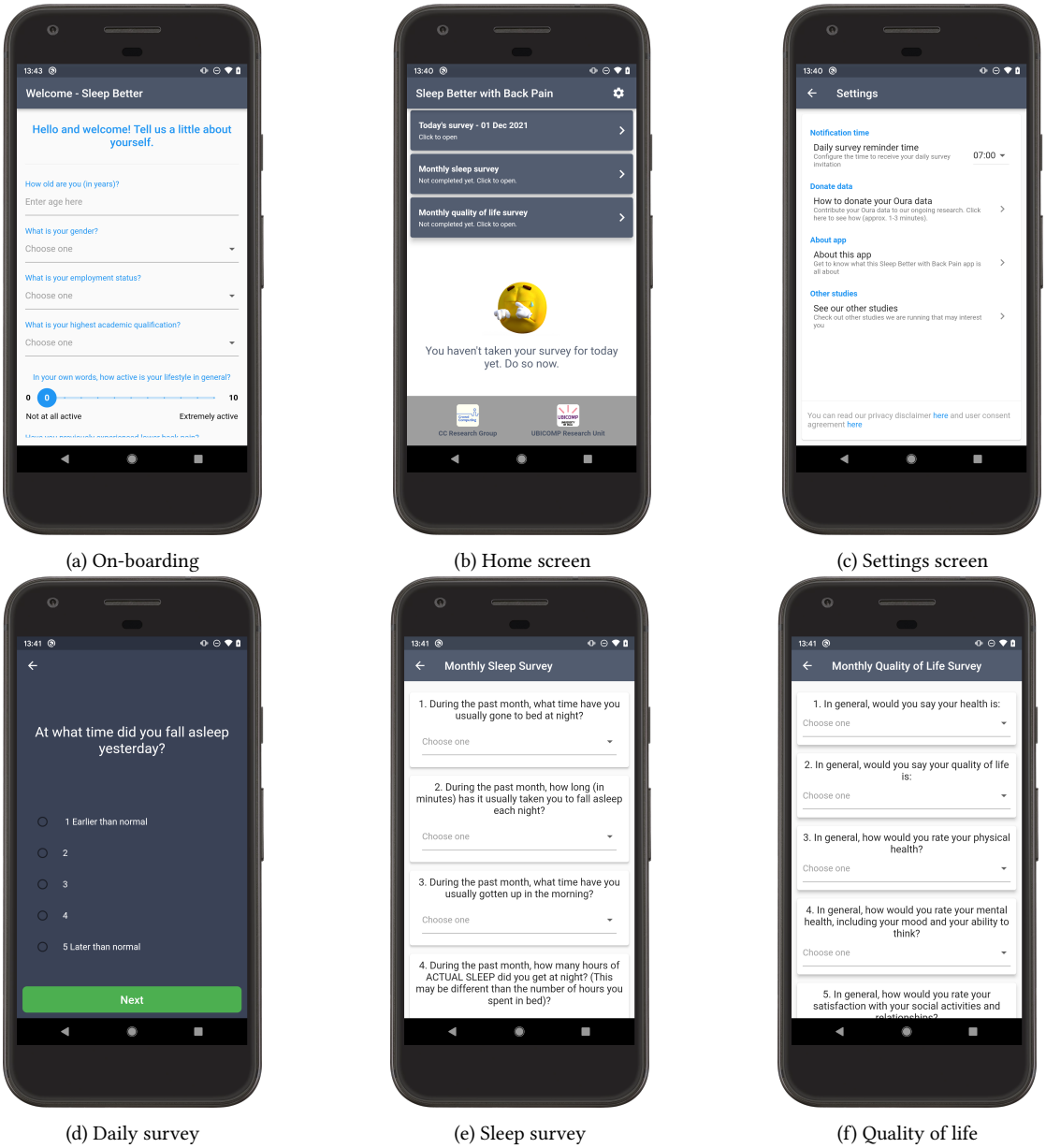
The app also has a settings screen (Fig. 1c) that enables the user to customize the application. Most importantly is the notification time for the delivery of daily reminders to answer a survey. Users receive daily push notifications at the selected time to remind them to take the daily survey. A set of two emojis (one happy face and one sad face) are displayed one at a time on the home screen indicating a completed survey (happy face) or a missing daily survey (sad face).

The "Sleep Better with Back Pain" app includes three in-app questionnaires: *daily survey*, *sleep survey*, and *quality of life survey*. The "daily" survey is taken daily while the "sleep survey" and "quality of life survey" are taken monthly.

3.1.1. Daily Survey

The daily survey comprised of the following items:

- Sleep time and wake up time, 5-point Likert-style item: 1 (Earlier than normal) - 5 (Later than normal)
- Time to fall asleep, 5-point item: 1 (Less time than normal) - 5 (More time than normal)
- Number of times waking up at night, 5-point item: 1 (Less than normal) - 5 (More than normal)
- How rested you feel after waking up, 5-point item: 1 (Less rest than normal) - 5 (More rest than normal)
- Severity of LBP pain, 1-point item: 0 (No pain) - 10 (Worst imaginable pain)
- How pain affected sleep and/or how sleep affected pain: Free-form text



(a) On-boarding (b) Home screen (c) Settings screen

(d) Daily survey (e) Sleep survey (f) Quality of life

Figure 1: Different user interfaces of the developed app.

3.1.2. Monthly Questionnaires

The monthly sleep questionnaire is a standardized Pittsburgh Sleep Quality Index (PSQI) questionnaire developed by Buysee et al. [26] as a self-report on subjective sleep quality over a period of four weeks. It consists of 19 items from which seven component scores that reveal the severity of various sleep problems are formed. These components include: sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, sleep medication, and daytime dysfunction.

The quality of life survey is a Patient-Reported Outcomes Measurement Information System (PROMIS-10) standardized questionnaire comprising of 10 global items that each represent a domain of health [27]. Global physical and mental health component scores are computed from the global items. Results from PROMIS-10 can be

used to assess patients' perceptions of their health. The physical health component scale comprises of four items on: physical health, physical functioning, pain intensity, and fatigue. The mental health component scale includes items on: quality of life, mental health, satisfaction with social activities and relationships, and emotional problems. Two of the global items (general health and social roles) are not used in the calculation of the physical and mental component scores.

3.1.3. Reminder Notifications

Notifications are delivered from our custom-built backend application through OneSignal [2] APIs. Data from the answered surveys are saved in an online Google Sheets document. User data is saved in a database hosted on our own servers. The "Sleep Better with Back Pain" mobile app is hosted on Google Play.

3.2. Pilot Experiment

Before embarking on the longitudinal deployment, we validated the feasibility of the app by conducting usability tests with four users within our research premises. During this session, we discovered some usability issues: 1) mandatory questions were not marked with an asterisk (*), 2) after completing a survey, the user is automatically directed to the main screen without any message to indicate the survey was complete, and 3) the choice of font type and color made visualization difficult. We also noticed technical issues such as 1) users finding it difficult to select 0 on the 0-10 slider scale, and 2) the keyboard not disappearing after users have finished typing an answer. These insights were useful in improving the app design and functionality before embarking on the longer deployment.

4. DATA COLLECTION

After making modifications to the app based on feedback from the usability testing session, we launched the app on the Google Play Store and published the study to our campus wide email lists. We did not specify any reward for participating in the study as we wanted to reach people who really wanted to use the app or were not motivated by any form of reward but were interested in understanding their sleep and LBP. We also reached out and recommended the study to previous participants of studies conducted by co-authors. The study run for a period of seven (7) months, from May to November 2021.

[2] https://onesignal.com

4.1. Participant Overview

A total of 35 people participated in our field study. Participants were mainly recruited from our local campus through our campus-wide email lists. However, we got additional participants via Google's Play Store as the app was published publicly there. Participant ages ranged between 20-68 (M = 38.03, SD = 12.94) with 20 females and 15 males. Participants had diverse academic qualifications and employment statuses. 20 hold a Master's degree or higher, 8 hold a Bachelor's degree, 2 hold a Vocational degree, and 3 hold a High School diploma while 3 did not disclose their educational information. Concerning employment, 21 participants identified as having a full-time job, 7 have a part-time job while 3 are unemployed, 2 are retired, and 2 did not disclose their employment status. None of the participants have had their back surgically operated by a doctor and the number of years lived with LBP ranged from 0-38 (M = 9, SD = 9.48). 20 participants have been clinically diagnosed with LBP, 8 have chronic sciatica, 5 non-chronic sciatica, and 20 have no sciatica.

We also inquired about how active participants' lifestyle was using a single 0-10 item (0 - not at all active to 10 - extremely active). The mean value was 5.51 (SD = 1.93). For inquiries about treatments and self-management techniques used in managing their pain, participants shared a variety of actions they take. Some of these include: "exercises", "yoga", "massages", "stretching", and "taking medication". A more nuanced analysis of these is outside the scope of this article.

5. Results

In the following sections, we present our quantitative and qualitative findings, focusing primarily on the effect of low back pain on the quality of sleep experienced by people living with LBP.

5.1. Quantitative Analysis

5.1.1. Relationship between sleep quality and pain intensity

We analysed the daily surveys (N = 1030) and computed Spearman's rank correlation to assess the relationship between the collected variables and "*well-restedness*". We noticed a negligible negative correlation between *pain intensity* and *well-restedness* ($r(1028) = -.12$, $p < .005$) and a negligible correlation between *wake up time* and *well-restedness* ($r(1028) = .08$, $p = .01$). Thus, the felt pain was not strongly associated with how well-rested participants felt the next morning. We also discovered a weak negative correlation between *sleep time* and *well-restedness* ($r(1028) = -.22$, $p < .005$). However, there was a

Table 1
Summary of the multivariate correlation matrix of PSQI component domains using Spearman's method alongside their significance values in brackets.

	Sleep quality	Sleep latency	Sleep duration	Sleep efficiency	Sleep disturbance	Use of sleep medication
Sleep latency	-0.32 (*)					
Sleep duration	0.36 (*)	-0.22 (0.18)				
Sleep efficiency	0.23 (0.16)	0.11 (0.49)	0.61 (***)			
Sleep disturbance	-0.17 (0.30)	0.44 (**)	-0.08 (0.62)	-0.15 (0.35)		
Use of sleep medication	0.48 (**)	-0.17 (0.29)	0.42 (*)	0.36 (*)	0.01 (0.93)	
Daytime dysfunction	-0.06 (0.71)	0.21 (0.19)	-0.10 (0.53)	0.06 (0.72)	0.34 (*)	-0.20 (0.21)

Signif. codes: 0 '***' 0.005 '**' 0.05 '*'

strong negative correlation between *sleep disruption* and *well-restedness* (r(1028) = -.41, p = < .005). Thus, and as can be expected, sleep disruptions are associated with how well-rested people feel in the morning. While these findings are not surprising, they are indicative of the app's feasibility in overall data collection.

5.1.2. PSQI

The global PSQI score from the responses (N = 36) of our study, which is the sum of all seven component scores has a range of 0-21 points with actual scores ranging from 4-16, an overall group mean of 8.4 (SD = 2.83, α = .68). For the individual components, each with a possible range of 0-3, the ranges were 0-3 except *sleep disturbance* which had a range of 0-2. For each component, as well as the global PSQI score, higher scores are an indication of worse sleep quality.

In Table 1, we examine the correlation of the PSQI components in our cohort using Spearman rank correlation. We found strong correlations between *sleep quality* and *use of sleep medication* (r = .48, p < 0.005), *sleep efficiency* and *sleep duration* (r = .61, p < 0.005), a moderate correlation between *sleep quality* and *sleep duration* (r = .36, p < 0.05), *sleep disturbance* and *daytime dysfunction* (r = .34, p < 0.05). *Sleep quality* had little to no effect on *daytime dysfunction* (r = -.06, p = 0.71) however.

5.1.3. PROMIS-10

We show the multivariate correlation matrix of the PROMIS-10 domains of the results (N = 36) of our study in Table 2. The mean physical health score of participants was 13.67 (SD = 3.01) and the physical health T-score of participants was lower (mean = 44.63, SD = 8.43) relative to the standardized mean T-score of 50. Similarly, the mean mental health score was 11.92 (SD = 3.23) and the mental health T-score of participants was lower (mean = 43.33, SD = 8.24) relative to the standard score. Thus our participants have significantly lower physical and mental function compared to the general population.

5.2. Qualitative Analysis

We analyzed 1030 responses to the open-ended daily questionnaire item (i.e. users' own elaboration on how pain affected sleep or how sleep affected pain) following a deductive thematic analysis process [28]. In using this analytical method, the first author first coded the most informative responses, generating the coding scheme which was then shared with the other co-authors. The authors held online meetings to discuss and resolve disagreements with the coding. They further identified aspects of the responses that would be most interesting to present and discuss. In subsequent sections, we present a subset of the findings from the analysis that we believe best fits the scope of this article.

5.2.1. Pain before, during, and after sleep

Participants expressed various degrees of pain felt prior to going to sleep, during sleep hours, and when they woke up in the morning. While there were reported feelings of pain prior to going to bed on some days, pain before bed did not always result to a painful sleep. One participant notes it was "*...difficult to fall asleep due to the pain but once I did, it didn't bother my sleep*" (Female, 42). In a similar vein, another participant exclaimed, "*...it was worst when going to bed, it did not bother me during the night*"(Male, 30).

On the contrary, some participants were quick to highlight the effect their LBP had on their sleep such as forcing them to stay awake at night for hours. One participant notes, "*I stayed up two hours at night because of pain in my hip*" (Male, 49) and "*I couldn't rest well due to pain at my back*" (Male, 30). There were days however where participants simply reported their LBP not having an effect on their sleep despite the presence of the pain. One participant stating that the "*...pain did not disturb my sleep*" (Female, 48).

It is also worth highlighting that good quality sleep positively affected participants' perception of pain in the morning, "*...sleeping helped pain*" (Female, 48). This was

Table 2
Summary of the multivariate correlation matrix of PROMIS-10 domains using Spearman's method alongside their significance values in brackets.

	Quality of life	Physical health	Mental health	Social activities	Physical functioning	Emotional problems	Fatigue
Physical health	0.74 (***)						
Mental health	0.60 (***)	0.33 (*)					
Social activities	0.52 (**)	0.45 (*)	0.57 (***)				
Physical functioning	0.17 (0.32)	0.31 (0.07)	-0.13 (0.45)	0.08 (0.66)			
Emotional problems	0.35 (*)	0.21 (0.22)	0.65 (***)	0.45 (*)	-0.22 (0.20)		
Fatigue	0.55 (***)	0.64 (***)	0.29 (0.08)	0.40 (*)	0.42 (*)	0.25 (0.15)	
Pain intensity	0.47 (**)	0.63 (***)	0.12 (0.49)	0.19 (0.26)	0.35 (*)	0.14 (0.42)	0.32 (*)

Signif. codes: 0 '***' 0.005 '**' 0.05 '*'

further supported by another who acknowledges to be "*...in a bit less pain this morning because I slept a bit better than usual*" (Female, 67) indicating a potentially positive effect sleep can have on one's LBP.

While we see several instances of sleep affecting pain positively and pain having a negative effect on participants' sleep, we also report that there were days where participants were confident that neither sleep nor pain had an effect on the other. One participant sums it all up, "*I didn't feel the effect from both sides*" (Female, 56). Participants could simply not tell if and how their sleep affected their pain or how their pain influenced the quality of their sleep. As such, experiencing pain did not stop them from having a good night's sleep, neither did having good quality sleep improve their perception of pain.

5.2.2. Weather, mattress, and sleep position

It was clear from the responses that other factors beside LBP affected participants' sleep. We noted that finding a "*...good position to sleep*" (Male, 40), a good support from the bed or mattress, and the need to "*...turn during sleep*" (Male, 38) were some of the concerns of a lot of participants. Participants also noted that the weather affected their sleep. This was particularly noticeable during the summer months where participants expressed a lack of or poor sleep due to hot weather. To some, the weather rather than their LBP affected their sleep, "*...my sleep last night was affected by the humid weather but not by the back pain*" (Female, 56). Another drew a connection between the weather and their felt pain, outlining how the heat could possibly be exacerbating the intensity of the felt pain, "*...it's mainly the heat that is making other things harder to deal with*" (Female, 67). Thus, to effectively manage one's pain, environmental factors must also be considered.

5.2.3. Exercises and active lifestyle

Some participants highlight being engaged in an active lifestyle and sports. To this, we noticed a report of an increase in pain or sleeplessness due to pain after an intense or strenuous workout, "*In the morning I felt some lower back pain and stiffness. It could be result from gym exercise*" (Male, 38). Interestingly, suffering from LBP did not stop participants from indulging in an active lifestyle (e.g. cycling, swimming, gardening, etc) or even participating in sports competitions although sometimes they have had to resort to medication to ease the pain afterwards as one participant notes, "*Yesterday I took part in an athletics competition (discus, javelin and hammer throw) and needed painkillers straight after*" (Female, 67).

6. Discussion

In this short report, we wish to introduce a simple mobile application along with some preliminary evidence speaking in favour of people being able to use it for providing data about sleep, LBP and their relationship.

The exploratory nature of our study is aimed at shedding more light on the LBP and sleep relationship conundrum. Sleep Better with Back Pain helps capture important self-reports on sleep and LBP that provides researchers with data and insights on this important health issue. The long term plan is to build a community powered application for improving the lifestyles of people living with LBP through timely reminders, recommendations, and coaching to motivate people to make healthier life choices that could improve both their low back pain and sleep quality.

6.1. Heterogeneity of Poor Sleep Factors

Overall, our results indicate the existence of a negligible relationship between felt pain and how well-rested participants felt in the morning. Indeed, this result is interesting as it could be an indication that people living with LBP have become so accustomed to their pain

such that it does not matter anymore. It is also an indication that the precise mechanisms that underpin the sleep and pain relationship remain unclear but are likely to involve multiple contributors such as depression [20], physical discomfort, neurotropic factors [29], as well as psychological factors [19] among others. Despite the pain felt prior to or during sleep, participants on average sleep well. On the contrary, we notice the emergence of factors such as *"sleep distruption", "weather", "active lifestyle", "medication", and "sleep position"* all having an effect on how well-rested people felt in the morning. One such factor worth expounding on is *"sleep distruption"*. Sleep disruption affected significantly how well-rested participants felt in the morning despite the intensity of their pain during the previous night. Thus, while participants' perceived sleep quality was not affected by the intensity of their pain at night, it was affected by the disruption of their sleep, disruptions which they identify to be caused non-exhaustively by *e.g.* sleep movements, bed or mattress, and environmental factors such as the weather.

However, the connection of some of these factors to pain is evident, *e.g.* sleep movements or uncomfortable sleep positions lead to sleep disruptions because participants' express feeling pain while moving in bed or laying in a particular position. Although participants often refer to a factor such as sleep disruption as a major cause of their poor quality sleep, one possible underlying reason for this disruption is their pain. The existence of and possibly, interconnection of these heterogeneous factors in assessing the sleep and pain relationship calls for a more holistic approach to investigating this issue.

6.2. Limitations

We acknowledge limitations in our initial exploration. We did not provide any form of reports, analytics, etc. nor incentives for participation to participants of the study, a possible reason for the low number of participants. Our focus in this study is to ascertain the feasibility of the core features of the app, and our results confirm that. While this affects the generalizability of our results, we argue that people have clear interest in LBP and sleep and are willing to contribute their data towards research in this sphere even when all they do is donate their data without getting any insights in return.

6.3. Towards a Future with LBP

Work is currently underway with the "Sleep Better with Back Pain" app, with new features and user-interface (UI) redesign. One such feature is the integration of daily, weekly, and monthly analytics for all survey items (daily, sleep, and quality of life surveys). We also foresee other features like an in-app community where we could crowdsource treatments for LBP and people suffering from LBP can suggest and view common LBP treatments used by community members. We envision the app to become an enabler of various studies with real users.

7. Conclusion

Our results show that the well-restedness of people living with LBP is influenced not only by pain at night but other factors such as sleep time, wake up time, and sleep disruptions. We also indicate that people are willing to donate their data toward sleep and LBP related research purposes. This study introduces a preliminary investigation into sleep tracking and low back pain using the "Sleep Better with Back Pain" app and communicates our initial results to the academic community in hopes to spark interest and discussion within the community.

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