

# Chapter 6

## iSenseYourPain: Ubiquitous Chronic Pain Evaluation through Behavior-Change Analysis



Matteo Ciman

### Introduction

In 1979, the International Association for the Study of Pain defined pain as “an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage” [1]. Pain is a subjective experience corresponding to an unpleasant situation that may be both physical and psychological. Acute and chronic pain are considered two distinct medical conditions. Acute pain is provoked by a specific injury or disease, generally lasts no longer than 6 months, and goes away when the underlying cause is gone [2]. Chronic pain, on the other hand, is a long-term condition. When associated with a specific injury or disease, it is considered a disease itself because it outlasts the normal healing time. It may even arise from a psychological state with no biological cause and with no recognizable endpoint [2]. In patients with chronic pain, overall quality of life is diminished [3], and for some patients, this pain can persist for one’s entire life. Aspects of quality of life that are usually influenced by chronic pain include, but are not limited to, sleep, cognitive and brain function, mood, mental health, and even sexual function [3–6]. Moreover, the amount one’s quality of life decreases is strongly correlated with the severity of chronic pain experienced [3], so that higher levels of pain lead to more significant reductions in quality of life.

The impact of chronic pain on quality of life calls for a reliable and continuous approach to pain monitoring and evaluation in order to provide the best possible support to patients. The aim of such an approach should be to assess patients’ pain throughout their lives in a timely and accurate manner without the use of self-reporting and to help patients cope with their situations so that they can avoid a considerable decrease in their quality of life. For this reason, this chapter presents *iSenseYourPain*,

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M. Ciman (✉)

Geneva School of Economics and Management, Center for Informatics, Quality of Life Technologies Lab, University of Geneva, Geneva, Switzerland

Department of Mathematics, University of Padua, Padua, Italy

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a system design that aims to gather continuous data about patients' behavior in order to understand how their pain experiences influence their lives. For example, the system seeks to determine if changes in sleep occur by measuring the number of hours and times of day when one sleeps, along with data such as the number of steps taken each day and the amount of time spent outside. The data is collected using ubiquitous devices and personal sensors integrated into patients' everyday lives. This way, patients do not need to carry intrusive, special medical devices to collect the information. By facilitating real-time assessment, the *iSenseYourPain* system is primarily designed to determine when increases in a patient's pain occur while measuring daily life activities and recognizing patterns of activity and pain experiences. In addition, the system aims to provide feedback to help patients manage pain exacerbations when needed with the help of their physician or relatives.

This chapter is structured as follows. Section 2 discussed the pain and its assessment via self-report methods, while Sect. 3, its assessment via devices. Section 4 presents the *iSenseYourPain* design choices and Sect. 5 concludes the chapter.

## Self-Reported Pain and Chronic Pain Assessment

Chronic pain requires frequent patient follow-up focusing on how pain is triggered [3], how it fluctuates with different behavioral patterns, patients' medication regimens and daily life contexts, and the ways pain influences overall health and life quality. Currently, the evaluation of chronic pain is generally based on the use of paper questionnaires and scales for which patients provide self-reports at predefined time intervals responding to a set of questions concerning their symptoms in the previous days or months. The most commonly used scales are described in what follows.

Boonstra et al. [7] have developed a scale model to evaluate pain based on the **Numeric Rating Scale**. A common challenge with this type of scale, however, is defining the different cut-off points for the mild, moderate, and severe pain categories into which the scale is divided. The **Visual Analog Scale** (VAS) is another common method for quantifying the severity of pain. It is a continuous outcome measure consisting of a scale 100 mm in length ranging from 0 to 100 with low- and high-end points corresponding to no pain and the worst pain. The VAS is easy to administer and has been validated for both adults and older children. It has also proven to be a reliable and valid technique to measure acute pain in emergency departments [8]. Meanwhile, the **Brief Pain Inventory** is commonly used to measure a patient's pain intensity and how much this pain influences their ability to live their everyday life. It consists of two different categories, namely pain intensity and pain interference [9]. The **Medical Outcomes Study Pain Measures** is another questionnaire that evaluates pain according to intensity, frequency, duration, and its impact on behavior and mood [10]. The *Oswestry Low Back Pain Disability Questionnaire* and the **Back Pain Classification Scale** are tools used by researchers and disability evaluators to evaluate low back functional disability or psychological disturbance [11, 12]. The **Pain and Distress Scale**, another frequently used

tool, is a measurement of mood and behavior that may be associated with acute pain. It does not describe the severity of patients’ pain itself but rather the physical and emotional reactions that can be attributed to limitations caused by pain in daily activities, including increased anxiety, depression, and decreased alertness [13]. In pediatric populations, **facial expression drawings** or “faces scales” are a popular method of assessing pain severity. A variety of faces scales exist, each of which uses a series of facial expressions to illustrate a spectrum of pain intensity. Faces scales are ordinal outcome measures consisting of a limited number of categorical responses ordered in a specific pattern. Although the optimum design of the facial expressions is frequently debated, the literature suggests that face-based rating scales are the preferred method of pain reporting among children. The **Wong-Baker FACES Scale** in particular has been implemented in multiple pediatric settings for pain assessment [14]. The *McGill Pain Questionnaire (MPQ)* is used to evaluate and monitor the pain over time, even to determine the effectiveness of any intervention [15]. The *Pain Perception Profile (PPP)* uses four different points of view to describe in the pain experience of each patient [16].

Finally, the **Chronic Pain Grade Questionnaire** is a multidimensional measure that assesses two dimensions of overall chronic pain severity: pain intensity and pain-related disability [17].

Table 6.1 provides an overview of the different pain scales, including the items to be filled out by the patient in each scale, the recall period, and the number of

**Table 6.1** Recap of different scales used to measure pain in patients

Scale name	Number of items	Type of pain Recall period	Number of output levels
The visual analog scale (VAS) [8]	1	Acute and chronic pain Now	10
The Brief Pain Inventory [9]	11	Acute and chronic pain Now, recent days and past weeks	11
The Medical Outcomes Study Pain Measures [10]	12	Chronic pain Past four weeks	12
The Oswestry Low Back Pain Disability Questionnaire [11]	10	Chronic pain	6
The Back Pain Classification Scale [12]	103	Acute and chronic pain	Checklist – 1
The Pain and Distress Scale [13]	20	Acute pain Recent days	4
The McGill pain questionnaire (MPQ) [15]	20	Chronic pain Now	1
Pain perception profile (PPP) [16]	37	Acute pain Now	4
Chronic Pain Grade Questionnaire [17]	7	Chronic pain	10

output levels provided by the scale based on the type of pain (acute or chronic) being assessed.

One of the aims of the assessment system that is proposed in this chapter is to realize a shift from a paper-based self-reporting approach to an automatic and ubiquitous one. Self-reporting requires time and cognitive effort to carry out and cannot be performed frequently, especially to the degree required for constant monitoring. The latter approach is based on the use of various ubiquitous devices that can constantly assess pain-related behavior changes. The *iSenseYourPain* system, which is presented in Sect. 4, is pervasive, ubiquitous, and non-invasive, requiring no input from the patient beyond an initial calibration phase and no equipment besides the technologies and devices already used in one's everyday-life, thus increasing patient acceptance. Before the presentation of the system, however, Section 3 provides a brief overview of how smart devices have been used for pain detection until now in order to contextualize the development of *iSenseYourPain*.

## Pain Detection Using Smart Devices

In the last decade, there has been an exponential increase in the number of mobile and ubiquitous devices in use, while a considerable number of self-monitoring applications have been introduced that aim to assess and improve individuals' overall quality of life. Several studies have pointed out that, for these solutions to be effective, they should be easy to use, customizable, and adaptable to the routine and lifestyle of each person, including their location, social interactions, and healthcare needs, while providing timely and personalized suggestions [18].

Given that chronic pain can have a severely detrimental impact on quality of life, several systems and platforms have been developed to provide support to patients suffering from it. One such platform is that of online peer-support forums. Several studies have been conducted that analyze their interactive use among patients with similar symptoms and diseases to promote the exchange of information and personal experience, provide distraction, and facilitate social or peer support. Meta-analysis of several trials in which online forums were leveraged in patients' care showed that patients who used such forums experienced a significant reduction in pain and anxiety, loneliness, and withdrawn behavior, as well as a greater willingness to return for treatment [19–21].

Besides online forums, the use of personal device systems is becoming increasingly common in the context of chronic pain. Kristjánsdóttir et al. [22] have developed a smartphone intervention system for women with widespread chronic pain. The intervention involves one face-to-face session between the patient and a nurse and four weeks of written communication between the patient and their therapist through the device. In Kristjánsdóttir et al.'s study of the system, participants filled daily smartphone diary entries to support their awareness and reflect on pain-related thoughts, feelings, and activities. The registered diaries were made available to a therapist who provided personalized written feedback to the patient based on

cognitive-behavioral therapy principles. The results suggest that a smartphone-delivered intervention with diaries and personalized feedback can reduce “catastrophizing” and prevent increases in functional impairment and symptom levels in women with widespread chronic pain following inpatient rehabilitation.

Meanwhile, multiple applications have been developed that focus on the management and assessment of chronic pain. *Painometer* [23] is an app that helps users assess pain intensity, including four different pain scales (including a faces scale) that can be used by patients to report pain experiences to their physician. Its main purpose is to encourage patients to report their pain and make the act of reporting more acceptable by offering a simpler and more accurate means of communication between patient and physician (see Fig. 6.1). The *iCanCope with Pain* [24] program is an integrated web and smartphone application for children and adolescents suffering from chronic pain. The goal of the application is to address the self-management needs of adolescents with chronic pain by improving access to disease information and symptom-management strategies while providing functionality for the self-monitoring of symptoms, the setting of personalized goals, pain coping skills training, chronic pain education, and peer-based social support.

Other studies in pain management have investigated the implementation of less ubiquitous or pervasive methods such as the use of external sensors such as electrocardiogram (ECG) or electroencephalogram (EEG) (as shown in Fig. 6.2). These devices have been used to collect data for biological values such as levels of oxygen saturation in the blood (SPO<sub>2</sub>), body temperature, heart rate (HR), heart rate

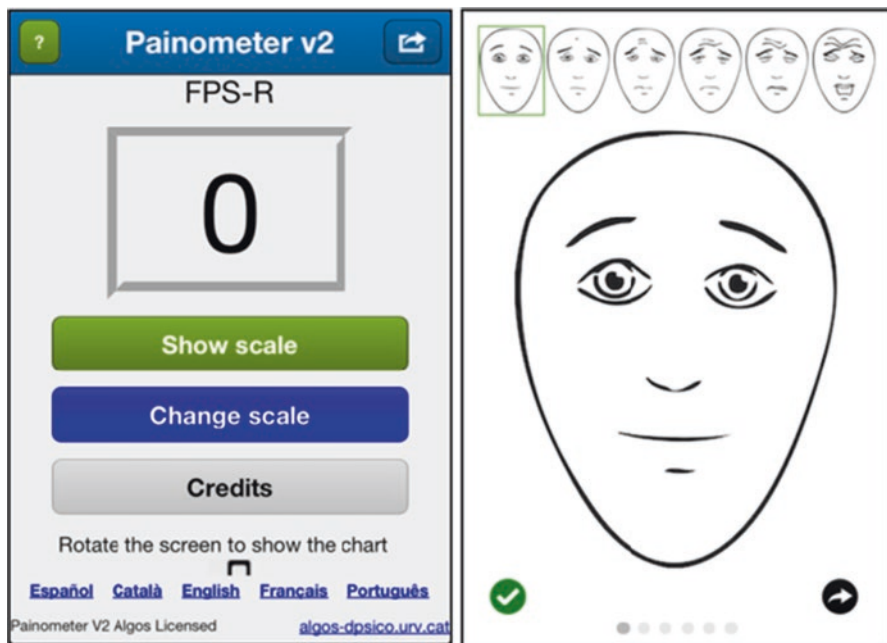


Fig. 6.1 Painometer App



**Fig. 6.2** Example of external sensor-based systems for pain assessment [25, 26]

variability (HRV), and galvanic skin response (GSR) [26, 27], as well as to perform simple electrocardiograms (ECGs) [25, 28] to detect and predict migraines in patients. Despite their effectiveness, it is clear that such approaches are far from easy to adopt for routine evaluation and monitoring of individuals' behavior metrics. Such external sensors are generally more invasive than personal wearable sensors, which in most cases are capable of performing the same measurements. For example, the Holter ECG monitor that is used to measure HR (shown in Fig. 6.2) is much more intrusive than a simple smartwatch, despite the fact that smartwatches are capable of monitoring HR continually with nearly the same accuracy.

As this section has demonstrated, current research and medical practices involving the use of smart devices for pain detection are either based on self-reporting and thus do not assess real-time changes in patients' pain experience, or they rely on external devices that are likely to affect or interfere in the everyday life of the patient. For these reasons, this chapter proposes a system designed to unobtrusively collect accurate and timely information about patients' behavior and identify correlations between changes in patients' everyday life activities and their experiences of pain. In contrast to assessments that are based on self-reporting, the system also aims to provide immediate evaluations and, eventually, to support patients before chronic pain dramatically impacts the quality of their life and the lives of those around them.

### ***iSenseYourPain*: System Criteria and Design Choices**

In this section, we outline the proposed *iSenseYourPain* system's main requirements and components, beginning with a discussion of previous research concerning smart devices that informs the system's overall approach. As indicated earlier in the

chapter, the system's main purpose is to use everyday devices to collect different types of data, analyze the data, and determine if a patient is experiencing a higher level of pain than normal and in which circumstances.

The design of the system and its components is based on the results of previous research that highlighted how behavior, and the interactions between a user and several daily-life smart objects, are influenced by emotional states and moods [29, 30]. Pain is not an emotion or feeling but a physical and/or mental state that may alter an individual's usual behavior. Such changes in behavior can be measured using several common devices, such as smartphones and other personal ubiquitous devices. The acquired data may have varying levels of granularity and encompass diverse modalities, ranging from the number of steps taken during the day to more complex measurements such as sleep quality or HR variability. Ultimately, the method of collecting data from everyday ubiquitous devices to assess the behaviors and behavior changes associated with pain meets the criteria that were initially set for the system: namely, the realization of automatic and minimally intrusive assessments that leverage patients' daily life environments.

The design of the *iSenseYourPain* system is presented in Fig. 6.3 below. The design includes four main components:

- A sensing component, which consists of a set of sensors and ubiquitous devices capable of collecting data about patients' lives that are embedded in the patient's environment (Fig. 6.3, left side);
- A self-report component occasionally used by the patient to self-report pain levels (Fig. 6.3, left side);

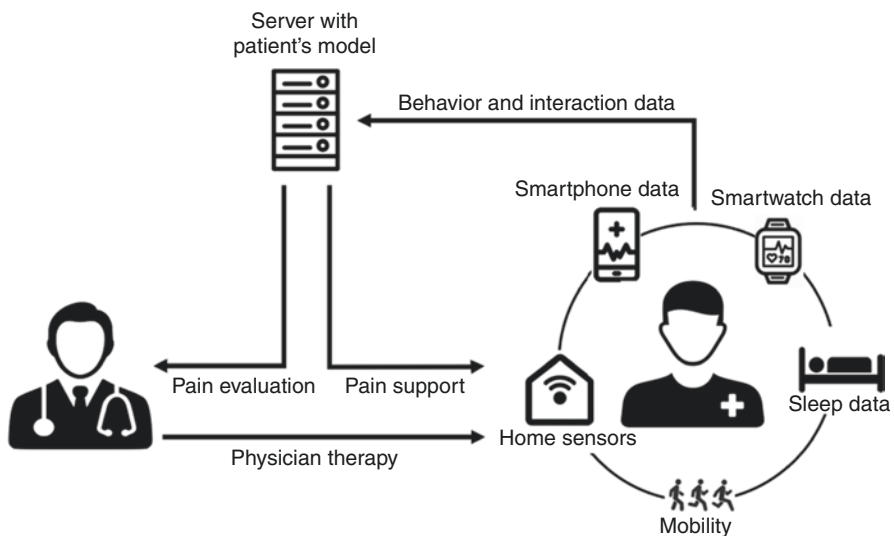


Fig. 6.3 *iSenseYourPain* system high-level design

- The core analytics component, which is hosted at a dedicated secure server and which analyzes the collected data to model and evaluate individuals' behaviors and correlate them with their pain levels (Fig. 6.3, middle);
- A visualization component for the physician and/or the individual's relatives that summarizes the patient's pain experiences and aspects of their behavior and indicates potential areas of focus for additional interventions or usual care (Fig. 6.3, right side).

### *Data Sources and Collection*

The system uses the data it collects to qualitatively and quantitatively describe the patient's behavior and define objective metrics in order to identify patterns linked to the patient's experienced pain levels. Table 6.2 below indicates how data corresponding to the different aspects of daily life potentially influenced by chronic pain can be sampled and collected within the system. In addition to data collected automatically through devices, a questionnaire based on the Chronic Pain Based Questionnaire (CPBQ) [17] is used occasionally to collect subjective pain experience data that is later correlated with data collected by the devices.

**Table 6.2** Aspects of daily life influenced by pain and corresponding data types and rates

Aspects of daily life	Type of data sources	Sampling rate	Other factors
General activity	Smartphone, hybrid home sensors	Hourly, daily	Highly variable between days, seasons, weeks
Mood	Smartphone, hybrid home sensors	Weekly, monthly	Highly subjective, additional data collected via self-reports
Walking ability	Smartphone, wearables	Daily	Strongly influenced by pain level
Work activity	Smartphone interactions, wearables/sensors	Daily, weekly	High variability according to the subject, additional data collected via self-reports
Relations with other people	Smartphone, hybrid home sensors	Daily, weekly, monthly	Number of interactions and time spent vary highly according to subject
Sleep	Smartphone, wearables	Daily	Influenced by various factors: Food, alcohol, physical activity, etc.
Enjoyment of life	Smartphone interactions, wearables/sensors	Daily	Highly subjective, additional data collected via self-reports
Perceived pain levels (CPBQ [17])	Structured questionnaire	Varies, frequency progressively decreases	Subjective



There are two important aspects of the design of the data collection methods: modularity and ubiquity. The collection methods are ubiquitous because all data sources are embedded within everyday life devices such as smartphones, wearables, the home environment, TVs, and appliances. This design choice aims to reduce the system's intrusiveness, leading to higher levels of acceptance from the patient while lowering the influence of the system itself on everyday behaviors. On the other hand, the system's modularity is essential to making it as scalable as possible and adaptable to the specific set of sensors or devices available to and used by each patient. As is explained in Sect. 4.2 below, each patient is characterized by a unique model corresponding to their everyday behaviors and pain-related behavior changes. These models are continually developed and evaluated based on the available sensors and devices and the data they collect.

As indicated above, patients are also occasionally asked to self-report pain levels by filling in a brief questionnaire on their smartphone in a way that leverages the Experience Sampling Method (ESM [31]). This self-reporting is carried out frequently at the beginning of the system use period, as it is important for creating and calibrating the patient's personalized model. The estimated duration of this initial calibration phase is one to three weeks, depending on the regularity of the patients' usual behaviors (such as sleep and activities) and the extent to which pain affects these activities. Once the model is pre-trained, the frequency with which patients submit self-reports via ESM will decrease, as the behavior-pain model will require only occasional smaller adjustments. In addition to the behaviors incorporated into the patient-specific model, there are some unusual behavioral indicators that may be strongly connected with pain experiences, such as the patient's staying a full day indoors or spending unnaturally long periods in bed. These behaviors are treated as "red flags" indicating a pain experience regardless of the patient's personalized model. When such unusual behaviors are detected by the system's technologies, the patient will be prompted to self-report so that the system can develop its pain model more accurately.

## ***Data Analysis and Modeling***

The core analytics component of *iSenseYourPain* is hosted at a secure server and focuses on providing analytics of the features derived from the system's various data sources. A model specifically derived for each patient is used to correlate behavior with the patient's pain levels. Table 6.3 provides examples of the features that can be derived from different data sources.

As every patient changes their behavior in different ways in response to pain experiences, the proposed system aims to identify the variations from normal behavior that are associated with pain for each particular patient. For example, sleep sensors can be used to model when a patients' quality of sleep decreases based on the number of hours the patient is sleeping, the number of times they wake up during the night, and the duration of time they spend awake. Similarly, patients

**Table 6.3** Examples of possible features derived from different data sources

Type of data	Source	Features
Smartphone interactions	Smartphone	Use time, screen interactions (touch, placement, strength of touch), time spent with different applications
Home life	Hybrid home sensors (for activity, light, noise, etc.)	Time spent inside/outside home, time spent in different rooms, types of activities performed at home
Sleep data	Wearables Smartphone	Sleep duration, timing of sleep during 24 h period, quality of sleep (especially sleep interruptions), time of different sleep phases (potentially inaccurate) Smartphone use around sleep and wake-up time
Physical activity	Wearables smartphone	Number of steps, time spent walking or inactive, timing of activities during 24 h period
Heart data	Wearables	Average HR, resting HR, time spent in different HR zones, HRV
Social interactions	Smartphone	Number of calls and messages sent/received (including social media usage), people met during the day (indoor/outdoor meetings, types of locations visited)

experiencing pain may take fewer steps outside their house than they normally do while constantly moving inside the house and changing their position (e.g., sitting or standing) or moving from room to room, all of which are behaviors that can be modeled by the system. Patients may also have different ranges of HR or HRV and smartphone habits. As each patient reacts to pain in different ways, the *iSenseYourPain* system uses the data collected during the initial training phase to understand each patient's behavior and develop a model that corresponds to their specific behavioral patterns.

## Conclusions

Chronic pain is considered a permanent medical condition. It may be due to a specific disease or injury, or it can arise from a psychological state, both of which may lead to chronic pain conditions with no predictable endpoint [2] and an overall decrease in quality of life. In patients with chronic pain, the behavioral changes associated with pain experiences tend to vary. Currently, these changes are generally assessed via self-reported measures that are infrequent, subjective, and memory based.

In this chapter, we have proposed the *iSenseYourPain* system design as a means to constantly evaluate the pain experienced by patients through assessment of observed behavioral patterns. *iSenseYourPain* collects data about patients' everyday behaviors and models relevant aspects of their daily life. Based on a specific model developed for each patient, it then assesses and predicts patients' pain levels based

on their behaviors. The system can inform a patient's physician about increased pain levels or inform their relatives about their potential care needs.

The *iSenseYourPain* system entails a significant contribution to the development of quality of life technologies [32] and the potential use of everyday technologies to quantify different aspects of individuals' lives [33]. Overall, implementing systems such as *iSenseYourPain* may facilitate the achievement of better life quality for patients and for those around them.

Future studies will be conducted that focus on implementing the system, both on the side of data collection and on that of the development of the patient model. Moreover, we plan to investigate which aspects of patients' daily lives that can be measured with personal and ubiquitous devices are most representative of behavioral change associated with pain experiences in specific types of patients.

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