UNIVERSITY OF CALGARY

Design and Evaluation of a Self-monitoring Application for Chronic Headaches

by

S. M. Waliur Rahman

A THESIS

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Abstract

Chronic headache sufferers use headache diaries to learn about their headache symptoms and triggers. But the existing headache diaries do not support identification of probable headache triggers which is a critical requirement for self-monitoring of headaches. The literature describes several applications that keep track of headaches, but none of them allow the patients to identify potential headache triggers by exploring the correlations between the self-tracked factors and the onset of headaches. In this thesis, a self-monitoring application is designed that supports reviewing of headache trends and enables interactive visual exploration of potential correlations between the headaches and the putative triggers based on temporal data analysis. The design of the application reflects the data collection and the analytical needs of the headache patients. The evaluation results suggest that the application can be useful for the headache patients to identify their potential headache triggers, and hence enable better self-monitoring of headaches.

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Dedication

I dedicate my M.Sc. thesis work to my beloved wife, Tahsina. You have always been there for me throughout this tough time of my life and inspired me to be confident with my studies. Thank you for your continuous encouragement.

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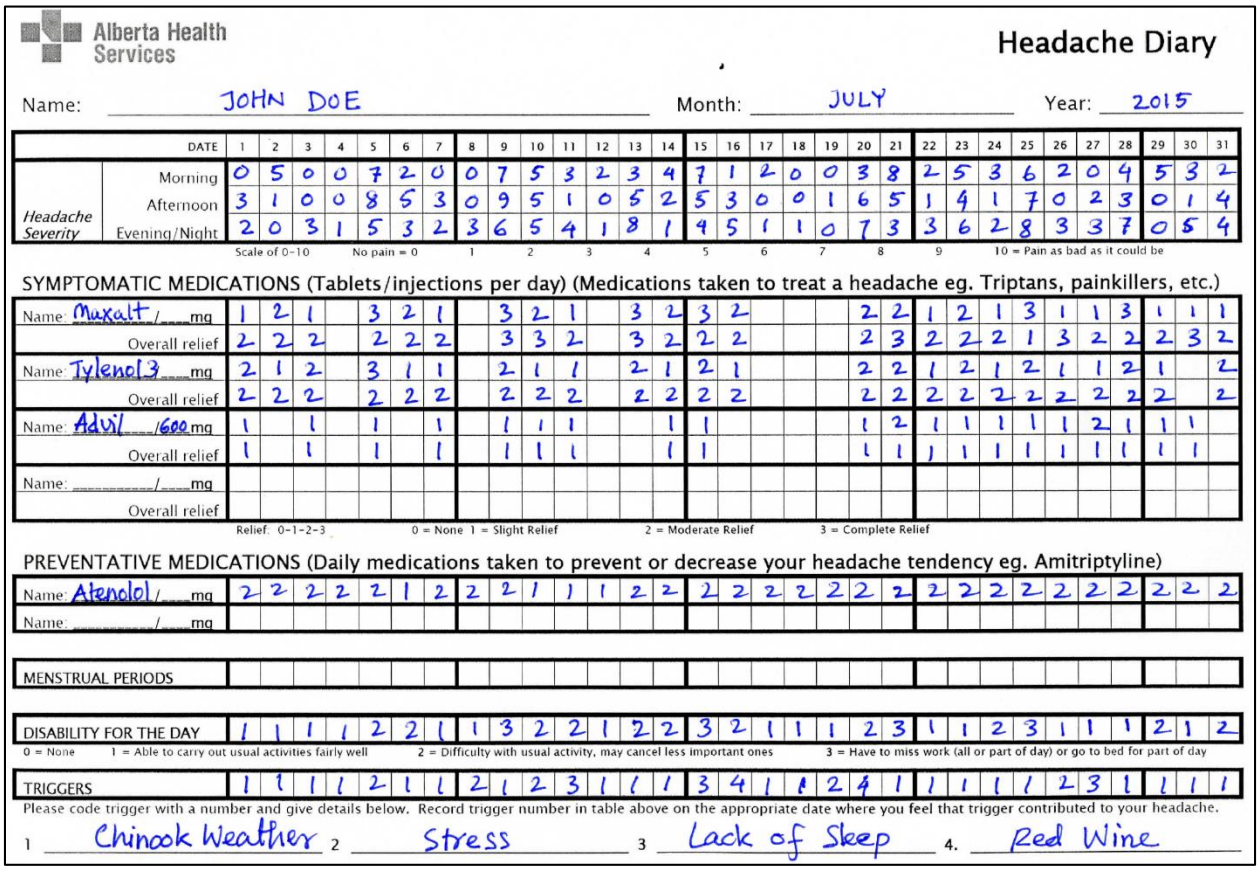
Chapter One: **Introduction**

1.1 Motivation

There have been increasing costs related to health care services over the past few years due to growing number of chronic conditions [61]. A chronic condition (e.g. chronic headache, diabetes) can be any long term illness or condition that impacts one's quality of life functionally and socially. An estimated 4% to 5% of the overall population suffers from chronic headaches [30]. The focus of my research is to help patients use computing technologies who are living with chronic headaches. Chronic headache patients have frequent headaches at an average of 15 days or more in a month [48]. Chronic headaches hamper the quality of everyday life (psychological aspects [2, 37], work/school functions [25, 46] and social communication [12]). Two of the major factors that influence the health outcome and health service utilization of an individual living with chronic illness (i.e. chronic headaches) are the type and quality of professional medical care that the individual receives and the everyday decisions and actions of that individual which affect his or her condition. While many aspects of professional medical care may be outside of an individual's control, most individuals have a substantial amount of control over their everyday actions, events and behaviors. Between visits to a healthcare provider, individuals need to manage their conditions in everyday life [27]. It is, therefore, essential for headache patients to know and understand how different factors in their daily life may affect or trigger headaches so that, based on this knowledge, they can bring changes in daily life routine to reduce the frequency and severity of headaches. A headache diary [28] is a tool for the patient from which he/she can extract insights and increase understanding of his/her own conditions. This is traditionally done using a paper-based diary (example in Figure 1.1). Patients can use headache diaries to track headaches and potential triggers. Yet, the resulting diary sheet (illustrated in Figure 1.1) is frequently haphazard

and relies on a patient's intuition and ability to formulate hypotheses about possible links between headache triggers and headache attacks.



Alberta Health Services

Headache Diary

Name: JOHN DOE Month: JULY Year: 2015

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Headache Severity — Morning	0	5	0	0	7	2	0	0	7	5	3	2	3	4	7	1	2	0	0	3	8	2	5	3	6	2	0	4	5	3	2
Afternoon	3	1	0	0	8	5	3	0	9	5	1	0	5	2	5	3	0	0	1	6	5	1	4	1	7	0	2	3	0	1	4
Evening/Night	2	0	3	1	5	3	2	3	6	5	4	1	8	1	4	5	1	1	0	7	3	3	6	2	8	3	3	7	0	5	4

Scale of 0-10 — No pain = 0 — 10 = Pain as bad as it could be

SYMPTOMATIC MEDICATIONS (Tablets/injections per day) (Medications taken to treat a headache eg. Triptans, painkillers, etc.)

Name: Maxalt /___mg	1	2	1		3	2	1		3	2	1		3	2	3	2				2	2	1	2	1	3	1	1	3	1	1	1
Overall relief	2	2	2		2	2	2		3	3	2		3	2	2	2				2	3	2	2	2	1	3	2	2	2	3	2
Name: Tylenol 3 ___mg	2	1	2		3	1	1		2	1	1		2	1	2	1				2	2	1	2	1	2	1	1	2	1		2
Overall relief	2	2	2		2	2	2		2	2	2		2	2	2	2				2	2	2	2	2	2	2	2	2	2		2
Name: Advil /600 mg	1		1		1		1		1	1	1			1	1					1	2	1	1	1	1	1	2	1	1	1	
Overall relief	1		1		1		1		1	1	1			1	1					1	1	1	1	1	1	1	1	1	1	1	
Name: _____/___mg																															
Overall relief																															

Relief: 0-1-2-3 — 0 = None 1 = Slight Relief 2 = Moderate Relief 3 = Complete Relief

PREVENTATIVE MEDICATIONS (Daily medications taken to prevent or decrease your headache tendency eg. Amitriptyline)

Name: Atenolol /___mg	2	2	2	2	2	1	2	2	2	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Name: _____/___mg																															

MENSTRUAL PERIODS																															

DISABILITY FOR THE DAY	1	1	1	1	2	2	1	1	3	2	2	1	2	2	3	2	1	1	1	2	3	1	1	2	3	1	1	1	2	1	2

0 = None 1 = Able to carry out usual activities fairly well 2 = Difficulty with usual activity, may cancel less important ones 3 = Have to miss work (all or part of day) or go to bed for part of day

TRIGGERS	1	1	1	1	2	1	1	2	1	2	3	1	1	1	3	4	1	1	2	4	1	1	1	1	1	2	3	1	1	1	1

Please code trigger with a number and give details below. Record trigger number in table above on the appropriate date where you feel that trigger contributed to your headache.

1 Chinook Weather 2 Stress 3 Lack of Sleep 4. Red Wine

Figure 1.1 Sample Filled Up Paper Based Headache Diary

The motivation behind my research is the need for an improved and effective tool that facilitates convenient data collection and more effective exploration/analysis of collected data for understanding possible correlations between headaches and their triggers among those that suffer from chronic headaches. In this thesis, I present, *HeadacheTracker*, a smartphone based application for self-tracking and self-monitoring of headaches.

1.2 Research Problem and Scope

Many patients suffering from chronic headaches do not fully understand what factors influence and affect the onset of their headaches. While some have a general sense of likely trigger factors, very few have a good understanding of what factors influence the headaches in personal contexts. From a self-monitoring point of view, existing applications do not allow patients to visually explore and analyze collected data interactively to identify potential factors responsible for their headaches.

My interest is to address this research problem – by designing an application that has headache tracking interfaces matching the needs of patients gathering the data (and healthcare professionals that may be helping them), and also has interactive visual analytic interfaces that can suggest and frame the data in ways that help patients to understand potential triggers of their headaches.

The scope of this research includes eliciting requirements for the proposed application and utilizing those requirements to develop a prototype application for chronic headache patients to allow interactive exploration and analysis of collected data. The scope also includes an in-lab evaluation study of the application to validate that the user requirements are met and to confirm the effectiveness of the application in fulfilling self-monitoring needs of chronic headache patients. This research falls into the broad scope of Human Computer Interaction (HCI), the study of how computer systems should be designed for human beings for successful interaction considering the usage context. Within this space, my focus is in ubiquitous/pervasive computing tools, which are used everywhere and anywhere in different contexts to facilitate in-situ tracking. The particular application area is Chronic Illness (Headaches), where the proposed work is based on personal informatics and personal visual analytics to enable headache patients easily track and identify

potential headache triggers by themselves. Figure 1.2 illustrates the focus of this research accordingly.

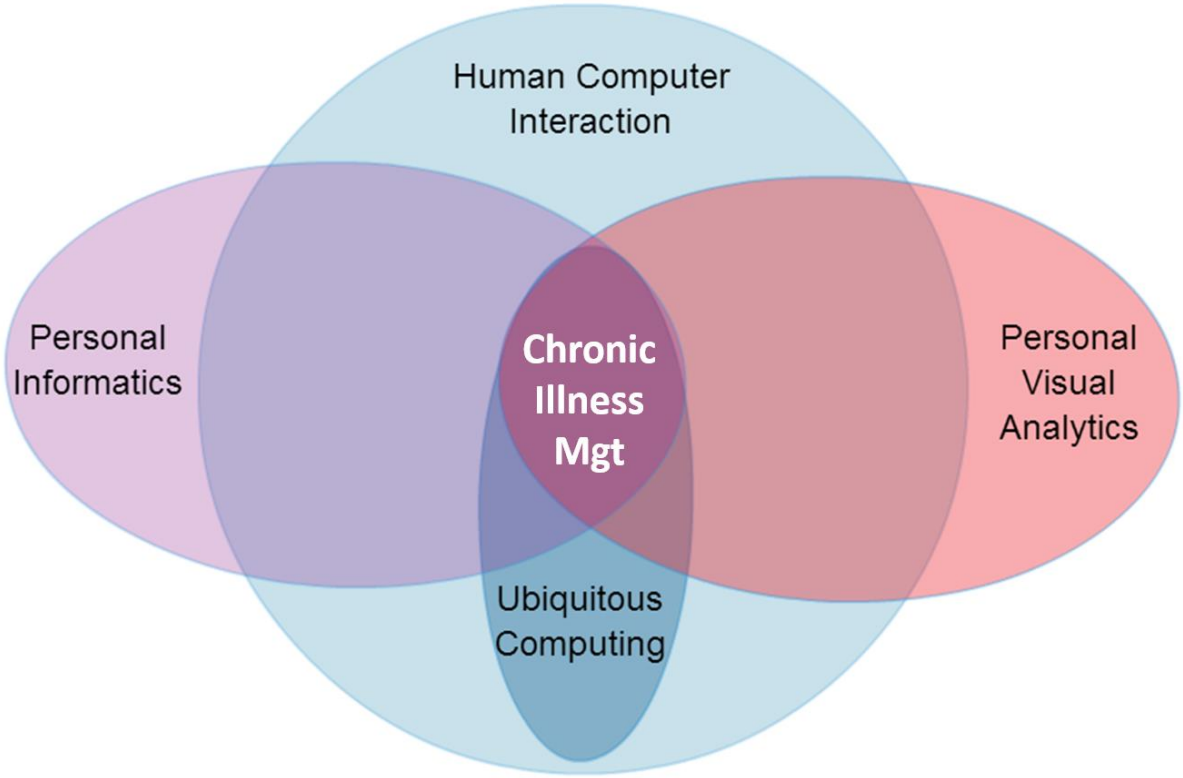


Figure 1.2 Illustrating Focus of the Research Work

1.3 Research Goal and Questions

My research goal is to help headache patients understand their potential headache triggers and headache trends by allowing them to interactively analyze and explore self-tracked headache data. The focus is on the design of an application (i.e. HeadacheTracker) for interactive exploration of self-tracked data rather than to provide conclusive medical insight about patient's headache condition. Headache data may consist of headache related parameters, daily activities or events that patients go through everyday life, weather data, medications etc. I state and briefly discuss the research questions below to achieve my research goal.

Research Question 1. *How should we design an application to facilitate headache data collection to address the needs of headache patients?*

It is unknown which factors (i.e. headache triggers) are important to a specific headache patient in personal context in addition to the typical list of factors provided by their healthcare provider. Beyond this, there are many factors that may influence data collection, including availability, frequency and visibility of data collection parameters. Understanding how and when patients expect to track and record data can aid in developing a deep understanding of how data collection interfaces should be designed to best fit into a patient's daily lifestyle. A poorly designed data collection interface would result in a poor adherence schedule, thereby reducing the quality of analysis that can be performed.

Research Question 2. *How should we design the visual analytic interfaces that facilitate exploratory analysis of potential headache triggers that may cause headaches?*

It is unknown what kinds of "analyses" patients may want to perform given their data. It is also important to understand how patients try to communicate their conditions with others (i.e. healthcare provider) and how data analytics help them to do so. This would help inform the design of analytic interfaces (e.g. interactive visualizations) that can help patients identify potential headache triggers. If patients are likely to explore data to find insights about their conditions, understanding their questions and expectations can also inform the design of analytical interfaces to a great extent.

By finding answers to the research questions, a set of requirements is to be developed for designing a self-monitoring application (i.e. HeadacheTracker) for chronic headache patients. The effectiveness of the design of the HeadacheTracker application for tracking and monitoring headaches can be evaluated based on perceived usefulness of the application.

1.4 Thesis Contributions

The contributions of the work discussed in this thesis are as follows:

1. Eliciting a set of requirements to design the HeadacheTracker for chronic headache data collection and analysis – the requirements are based on a qualitative study of user (chronic headache patients) needs.
2. Illustrating how the requirements mentioned above are analyzed and utilized to design and develop a functional prototype application (i.e. HeadacheTracker) for chronic headache patients.
3. Demonstrating how the HeadacheTracker can help the headache patients perform data tracking and analysis in their everyday life.
4. Discussing design implications and how it helps inform the design process of self-monitoring application for chronic headaches.

1.5 Organization of the Thesis

A concise background of the research for this thesis is presented in this introductory chapter. The research goal and scope are discussed and a brief thesis contribution is outlined. The remaining chapters for this thesis are organized as follows:

Chapter Two: Background and Related Work - describes general background of chronic headaches and headache triggers and a detailed overview of relevant work to create the context and foundation for the research. This includes personal informatics and personal visual analytics approaches for self-monitoring, discussion of self-monitoring applications for chronic headaches and shortcomings of existing applications with respect to analysis and exploration of collected data.

Chapter Three: Requirements Elicitation Study - describes the approach, methods and results of the requirements elicitation study for the HeadacheTracker application. The requirements define the underlying criteria for designing the application for tracking and analyzing headache data.

Chapter Four: Design and Development of the HeadacheTracker - discusses the approach and methods to convert requirements into tangible design by exploring and comparing alternatives that reflect the requirements. The chapter also describes the development of the HeadacheTracker in terms of system architecture and database model and provides an overview of all the functionalities.

Chapter Five: Evaluation Study of the HeadacheTracker - contains the evaluation study and results that explain how effective the HeadacheTracker application is for chronic headache patients. It also outlines how the results are the evidence for achieving the research goals.

Chapter Six: Conclusion - discusses the limitations of the research, summarizes overall contributions and results of the thesis and proposes future research direction with concluding remarks.

Chapter Two: **Background and Related Work**

In this chapter, I provide a primer on chronic headaches, and then present an overview of the existing work related to my thesis.

In Section 2.1, I describe chronic headaches, headache triggers and the nature of the relationship between headache attacks and headache triggers. In Section 2.2, I discuss how the headache diary plays an important role in chronic headache management. I describe how in a community health program, clinicians emphasize the self-monitoring of headaches using headache diaries for diagnosis and treatment. The section also describes the evolution of headache diaries for self-monitoring of chronic headaches.

The major output of this thesis is the HeadacheTracker, a smartphone-based personal informatics application for self-monitoring of chronic headaches. In Section 2.3, I discuss foundational concepts of personal informatics, associated challenges and how personal informatics can be used for self-monitoring of headache data.

One fundamental step for producing visualizations is to extract semantic information from data. The HeadacheTracker uses conditional probability and relative frequency notion of probability to extract knowledge about the possible correlations between headache triggers and headache attacks. In Section 2.4, I describe conditional probability and relative frequency in the context of this thesis.

The HeadacheTracker uses self-tracked data to produce several interactive visualizations. In Section 2.5, I explain basic principles of information visualization and describe emerging research in personal visual analytics that govern the design of the interactive visual exploration of data of the HeadacheTracker application.

In Section 2.6, I provide an overview of existing applications related to headache tracking and monitoring, find gaps or improvement areas in those and discuss how I have addressed the improvement areas in my research.

2.1 Chronic Headache and Headache Triggers

A "Chronic Headache" is a headache that occurs 15 or more days in a month [48]. Chronic headaches may not be fully cured but can be well managed and controlled using various clinical and non-clinical methods [15]. Different types of headaches [16] have different symptomatic characteristics [48]. Individuals may have single or multiple types of chronic headaches at the same time. A headache attack occurs due to changes in the headache patient's "internal" and/or "external" environment [43]. An example of internal change can be the abrupt decline in estrogen (a hormone) levels occurring with menstruations, whereas example of an external change can be the effect of weather changes. "Headache trigger" is a commonly used term to label any such "internal" and/or "external" influencing factor that is assumed to trigger the onset of headaches. Some common headache triggers are stress, anxiety, overexertion, caffeine, alcohol, odors, weather, and changes in eating or sleeping habits [7].

Headache triggers may remain same or may change from one headache attack to the next for the same person, identified triggers may vary among headache patients and triggers may start headaches quickly or slowly [7, 43, 60]. Research indicates, "*singularly, the triggers are generally necessary but may not be sufficient, (i.e. not powerful enough to bring on headache by themselves) and, hence, compounding of those triggers is usually required*" [51]. To help headache patients identify their headache triggers, it is necessary to let them know not just how often a trigger is followed by a headache but also how often it is not. Having identified trigger-headache associations, a headache patient may further determine which triggers are likely to be causative

for him/her, either alone or in combination with other headache triggers. Therefore, the first challenge for headache patients is to find the associations between potential triggers and the occurrence of headaches and the second challenge is to establish that the triggers do, indeed, contribute to the occurrence of chronic headaches.

2.2 Headache Diary for Self-Monitoring of Chronic Headaches

Chronic headache patients are often referred by general medical practitioners to a specialized headache clinic for treatment. The Calgary Headache Assessment and Management Program (CHAMP) under Alberta Health Services is one such specialized clinic that offers workshops, lectures and education geared towards the headache patients [62]. CHAMP teaches headache patients all the necessary skills to manage their own headaches. In an introductory and mandatory headache education session by CHAMP, headache patients are introduced and encouraged to track headache data using a headache diary to understand patterns of their headaches [7]. Collecting and analyzing headache data is particularly useful for people with chronic headaches, whose headache attacks usually occur in response to unidentified triggers [4]. Usually, headache patients guess or assume their headache triggers but are unsure of them until they track and analyze their headache data. Consistent with the International Headache Society guidelines [16], CHAMP recommends a paper-based diary for its patients to self-track or self-monitor headaches as patients go through everyday life. Self-monitoring is the process of tracking and reflecting on one's own behaviors and feelings [19]. The self-monitoring process involves individuals' collecting and reflecting on personal data. Thus, self-monitoring of chronic headaches also depend on effective data collection and analysis of collected data. The CHAMP headache diary allows patients to track headache severity, medication intake, menstrual cycles, overall disability due to headache and perceived headache triggers (sample in Figure 1.1). A headache

patient usually tracks only the factors that they assume to trigger their headaches. The problem with perceived triggers is the fact that they are completely based on guesswork of the patient. The perception can go wrong since associativity of perceived headache trigger with headache attack is not based on temporal analysis and identifying triggers is complex due to headache trigger characteristics mentioned in the previous section.

Generally, headache patients are not educated in data collection and analysis as opposed to Quantified-Selfers [8] who diligently and routinely track many kinds of data about themselves. By keeping a headache diary, a chronic headache patient is exposed to the opportunity to learn from the collected data about trends or patterns of headache attacks. A variety of other methods may be applied to headache self-monitoring, for example, mechanical or electronic devices, or sophisticated electronic or computerized diaries. While paper diaries (sample in Figure 1.1) have traditionally been used for self-monitoring of headaches [50], advances in computing technology have expedited prevalent use of electronic diaries (e-diaries) [29, 34, 53, 54]. An e-diary offers accuracy of data collection, increased adherence to daily tracking of relevant data, acceptability and efficiency over a paper-based diary [1, 6, 21, 55]. As patients often need to manage their headaches outside of the controlled clinical settings, it is challenging for them to track the traditional indicators of headache symptoms and also contextualization of those indicators in their daily activities and lifestyle. The challenges present unique opportunities for “ubiquitous” or “pervasive” computing technologies to expedite wide spread use of e-diaries. Ubiquitous means the something is available anywhere anytime, while pervasive means the computing is permeated in the environment. This means, the access to computing and communications resources is ubiquitous, while different technologies like small sensors and handheld devices (small, easy to use) have permeated in our surroundings [35]. The pervasive nature of these devices allow for in-

situ data collection [9]. Electronic or computerized headache diaries available for these pervasive handheld devices fall under broad scope of personal informatics applications. Recent research indicates the potential effectiveness of personal informatics applications for management of chronic illness [26]. The next section gives an overview of personal informatics discipline.

2.3 Personal Informatics

Personal informatics (PI) applications "*help people collect personally relevant information for the purpose of self-reflection and gaining self-knowledge*" [22]. Self-knowledge has ample benefits, including enabling self-control and promoting healthy lifestyle behavior [42]. There are five stages in self-tracking process [22]:

1. Preparation: in this stage one needs to determine which information to collect, which tools to use and which questions to investigate.
2. Collection: in this stage one needs to collect the data either manually or with a tool and store it on paper or digitally.
3. Integration: this stage involves processing the data to extract relevant trends, patterns and episodes.
4. Reflection: analyze the integrated data to obtain insight about self.
5. Action: suggest eventual changes in behavior.

Stages are iterative, so it is normal to go back and forth through them multiple times as in each stage difficulties may arise. Some of the biggest barriers in self-tracking process are:

- Not knowing what to track or what to expect to gain from tracking.
- Choosing wrong tools that do not meet user goals.
- Having to perform the collection manually. This means that often people forget, get tired, or are inaccurate in their tracking and give up at the end.

- Lack of expertise and knowledge in how to integrate, process and reflect on the collected data.

Users of PI applications switch between two modes based on their needs: discovery and maintenance [23]. When in discovery, users try to make sense of the data from different perspectives and look for insights or pattern about their behavior. During maintenance, users track specific aspects of their behavior in order to change it. Although, not all the PI applications need data visualizations, but when they do, most of those PI applications rely on traditional data visualization charts for reflecting on the data. Alternative visualizations have been proposed, ranging from abstract art [13, 40] to virtual objects [24]. Visualization concepts are discussed separately in more detail in Section 2.5.

In the context of my thesis, HeadacheTracker application allows the users to perform collection, integration and reflection phases of self-tracking process. Overall, the application allows users to interchange between maintenance and discovery mode. The application mostly uses traditional charts for visualizations based on user requirements.

2.4 Conditional Probability and Relative Frequency

The probability of an event is the degree of the likeliness that the event will occur. Probability can be a number between 0 and 1. In probability measure, 0 indicates impossibility and 1 indicates certainty. A higher probability of an event asserts higher likeliness that the event will occur. For example, probability of having a headache today is 0.9 means there is a very high possibility that a headache will occur today. The probability of an event A is denoted by $P(A)$.

In the context of my thesis, I want to determine if any factor (e.g. stress level, coffee intake) tracked by the patient is contributing to the onset of headaches for that patient. That means, the onset of a headache can be considered as the potential effect of a prior event (a probable cause).

The cause and the effect are two dependent events in the timeline. Two events are considered dependent if the outcome or occurrence of the first event affects the outcome or occurrence of the second event so that its probability is changed. For example, from a bag of colored marbles, each time a marble is removed, the chances of drawing out a certain color (marble) will change for the next removal. This is the fundamental concept of conditional probability. The conditional probability of an event B is the probability that the event will occur given the knowledge that an event A has already occurred. The conditional probability is written as $P(B|A)$, notation for the probability of event B given event A has occurred.

Conditional probability can be used to estimate how likely a putative trigger is responsible (or not responsible) for the onset of headaches. For example, if a patient tracks coffee intakes and headaches simultaneously and if the headaches are (observed) effects and coffee intakes are (hidden) causes, the probability of having headache given coffee intake is $P(Headache|Coffee)$. In this context, coffee intakes and headaches are considered same day events. Similarly, the probability of having no headache given coffee intake is $P(\neg Headache|Coffee)$. As I have discussed in Section 2.1, both coffee intakes followed by headaches and coffee intakes followed by no headaches should be taken into account to understand how likely the coffee intakes are responsible for headaches. I have used the "relative frequency" approach to estimate $P(Headache|Coffee)$ and $P(\neg Headache|Coffee)$ based on temporal analysis of recorded headache data. Relative frequency is how often an event happens divided by all the outcomes. I have used relative frequency because sometimes a probability cannot be calculated by just looking at the situation. For example, the probability of winning a cricket match cannot be calculated by assuming that win, lose and draw are equally likely. Instead, previous results in similar matches can be taken into account to *estimate* the probability of winning. There is prior knowledge (based

on data) about the frequency of occurrence of coffee intakes $P(Coffee)$ and the frequency of occurrence of headaches $P(Headache\ after\ Coffee)$ after coffee intakes within same day. Based on these knowledge, $P(Headache|Coffee) = \frac{P(Headache\ after\ Coffee)}{P(Coffee)}$ using the relative frequency approach for conditional probability estimation. $P(\neg Headache|Coffee)$ can be estimated in a similar manner. Table 2.1 shows example data to illustrate the concept. $\boldsymbol{C}$ denotes number of days a user had coffee within a total of 17 days and $\overline{\boldsymbol{C}}$ denotes coffee free days within the same 17 days. $\boldsymbol{H}$ denotes the number headache days within the same 17 days and $\overline{\boldsymbol{H}}$ denotes the number of headache free days within the same 17 days. Based on temporal analysis, if the number of headache days followed by coffee intake on the same day is 5 and the total coffee intake days are 8, then $P(Headache|Coffee) = \frac{5}{8} = 0.625$ (62.5%).

Table 2.1 Calculating Conditional Probability using Relative Frequency

	$\boldsymbol{H}$	$\overline{\boldsymbol{H}}$	**Total**
$\boldsymbol{C}$	5	3	**8**
$\overline{\boldsymbol{C}}$	7	2	**9**
Total	**12**	**5**	**17**

As I have mentioned in Section 2.1, often a combination of potential headache triggers are required to trigger a headache. Based on temporal analysis of the recorded data, frequency of headaches (or no headaches) followed by coffee intakes and stresses on the same day can be calculated. The order of coffee intake and stress in the timeline is considered insignificant but the number of times a headache attack is followed by both of them provides the relative frequency $\frac{P(Headache\ after\ Coffee\ and\ Stress)}{P(Coffee\ and\ Stress)}$ which can be used to estimate the probability of headaches given coffee intakes and stresses. The combined effect of two putative triggers can be calculated following this approach.

2.5 Information Visualization and Personal Visual Analytics

In this section, I discuss some basic concepts about information visualization and personal visual analytics that governs the design of visual analytic interfaces (discovery mode with respect to PI) of the HeadacheTracker application.

Information visualization is the process of using texts, shapes and colors to facilitate understanding of a complex dataset. When designing a visualization, the starting point is to determine which questions need to be answered [31]. Typical questions include: What differs from the normal pattern? Are there any trends? Is there a correlation between variables? An insight is an answer provided by visualizations that leads to a deeper understanding of the dataset being visualized [64]. For example, looking at a line chart gives a simple insight of the increasing or decreasing trend over time. Looking at a flow chart, the user can get insight of the flow of objects by following the connecting lines and symbols. Insights can be of different types [36]:

- Analytic insight: comes from exploratory analysis and extrapolation of data.
- Awareness insight: based on maintaining awareness of a particular data stream to have a sense of shifting patterns in the data.
- Social insight: insight about social networks, social situations and social life.
- Reflective insight: insight about oneself and his/her surroundings.

Computer-generated visualizations allow the user to interact and explore specific characteristics or insights of a dataset. A common interaction pattern is "*overview first, zoom and filter, then details on demand*" [47]. Personal Visual Analytics (PVA) is an emerging research area that deals with personal data visualization based on computer-assisted data analysis. According to Huang, et al., "*PVA is the science of analytical reasoning facilitated by visual representations used within a personal context*" [59]. The objective of PVA is to make appropriate use of the power of

visualization and analytics together to enable reflection on the self-tracked data for people who have little experience with data analysis, visualization or statistics. Research trends in PVA include enabling exploration for curiosity, supporting awareness for action, taking care of family and reflecting on communities [59]. Visualizations in the HeadacheTracker application support both the data exploration for curiosity and awareness for action.

2.6 Overview of Existing Headache Diary Applications

Self-tracking and monitoring of chronic headaches using a PI or PVA application may enable recognition of temporal headache patterns, allow individuals to become informed and actively self-manage headaches [26, 63]. Fulfilling these self-monitoring objectives largely depend on two critical factors, the ability to track all parameters that a patient needs to track and the capacity to look for patterns or trends by aggregating, searching, filtering and relating collected parameters. The critical aspects of headache data collection using a PI approach can be allowing a patient to track anything that he/she feels significantly responsible for his/her headaches in a timely and accurate manner, providing early feedback to help identify what to track and maximizing the benefits of manual tracking [8]. In academic research, e-diaries (PI applications) were investigated to measure compliance level and adoption rate of e-diaries over paper diaries [52] but temporal pattern analysis and interactive exploration of data to identify an individual's headache triggers are still relatively unexplored areas. A recent systematic review identified 38 smartphone applications for headaches in Canadian mobile app stores for iOS and Android platforms [18]. These applications lack user interfaces that facilitate analyzing collected data from different perspectives to identify potential headache triggers. Another very recent application for migraine tracking and monitoring is cited in [51] that employed statistical analysis to measure associativity of headache triggers with headaches based on p-value. The overall quality of these headache diary

applications with respect to effective data collection for identifying headache triggers is insufficient to address all the self-monitoring needs of headache patients [17]**.** Existing PI applications for self-monitoring of chronic headaches have several limitations, including not using a participatory design process [49] leading to reduced application usability, recording insufficient data to provide understanding of headache patterns [52] and not providing suitable means of visualizing, exploring and analyzing collected data to find relationships and trends associating headaches with headache triggers [26, 39].

Seven evaluation criteria are defined in [18] to evaluate headache diary apps found in Canadian iOS and Android app stores. Ideal headache diary apps -

1. should involve clinicians to utilize their expertise,
2. should be tested with users to ensure the diary is feasible and reliable method of data collection,
3. should allow users to collect clinically relevant headache variables,
4. should be usable for end users,
5. should include customizable options for user defined data collection,
6. should include reports linking multiple parameters, and,
7. should have the ability to export data from the app.

In the context of my thesis, criteria 1 to 6 have been followed in the design of the HeadacheTracker application although these criteria are not enough to meet the research goal. An ideal headache diary application should allow and encourage headache patients to track their daily activities, events and actions in addition to known clinically relevant headache variables (criteria 3). Such tracking opens the way for analyzing associativity of these factors with headache attacks which is particularly useful for understanding the correlation of different headache triggers with

headaches. Criteria 4, usable apps, in [18] is defined as easy to use and easy to understand interface. In my thesis, I go beyond this definition of "usable app" by defining a set of requirements based on user research.

Only 7 headache diary apps in [18], having the option for tracking clinically relevant variables, have met 4 or more app criteria mentioned above. Apps that met at least 4 or more criteria are iHeadache, Headache Diary (ecoHeadache), Headache Diary Pro (by Froggyware), Headache Diary Pro (by Appcellent Gmbh), Migraine Diary, PainCal and A Migraine Diary for You [18]. Two particular aspects of interest in the context of my thesis are tracking in-situ daily life data (e.g. sleep, exercise, stress etc) and the interactive exploration of data that might show potential relationships between headaches and headache triggers. None of the mentioned applications have options for collecting patient's everyday life data. Some applications allow to track perceived triggers (e.g. Figure 2.1 (b)) which is completely based on user's guesswork. Temporal pattern analysis cannot be performed on them since time is not tracked by these applications with respect to the trigger events. Figure 2.1 shows screenshots of few data capture interfaces of the iHeadahce application which is one of the highest scoring app according to the evaluation criteria:

Figure 2.1 Data Capture Interfaces of iHeadache: (a) Headache Entry, (b) Perceived Trigger Entry, (c) Symptom Entry

Probably the most advanced (and most recent) personal informatics application designed so far for self-monitoring of chronic headaches is "Curelator Headache" which is mentioned in [51]. It is a web-based platform that aims to guide users with migraine to identify associations between triggers and headaches. It also allows users to test behavioral modifications to determine if a presumed migraine trigger is truly causative. Users can track day to day activities and events along with headache attacks using a smartphone application. User entered data is then analyzed by a proprietary analytical engine using statistical modelling. When enough data has been entered (45-90 days), the application determines associations between single or combinations of triggers and the occurrence of migraine headaches. Figure 2.2 shows a visualization of "Curelator Headache" that shows the association of headache triggers with headache attacks.

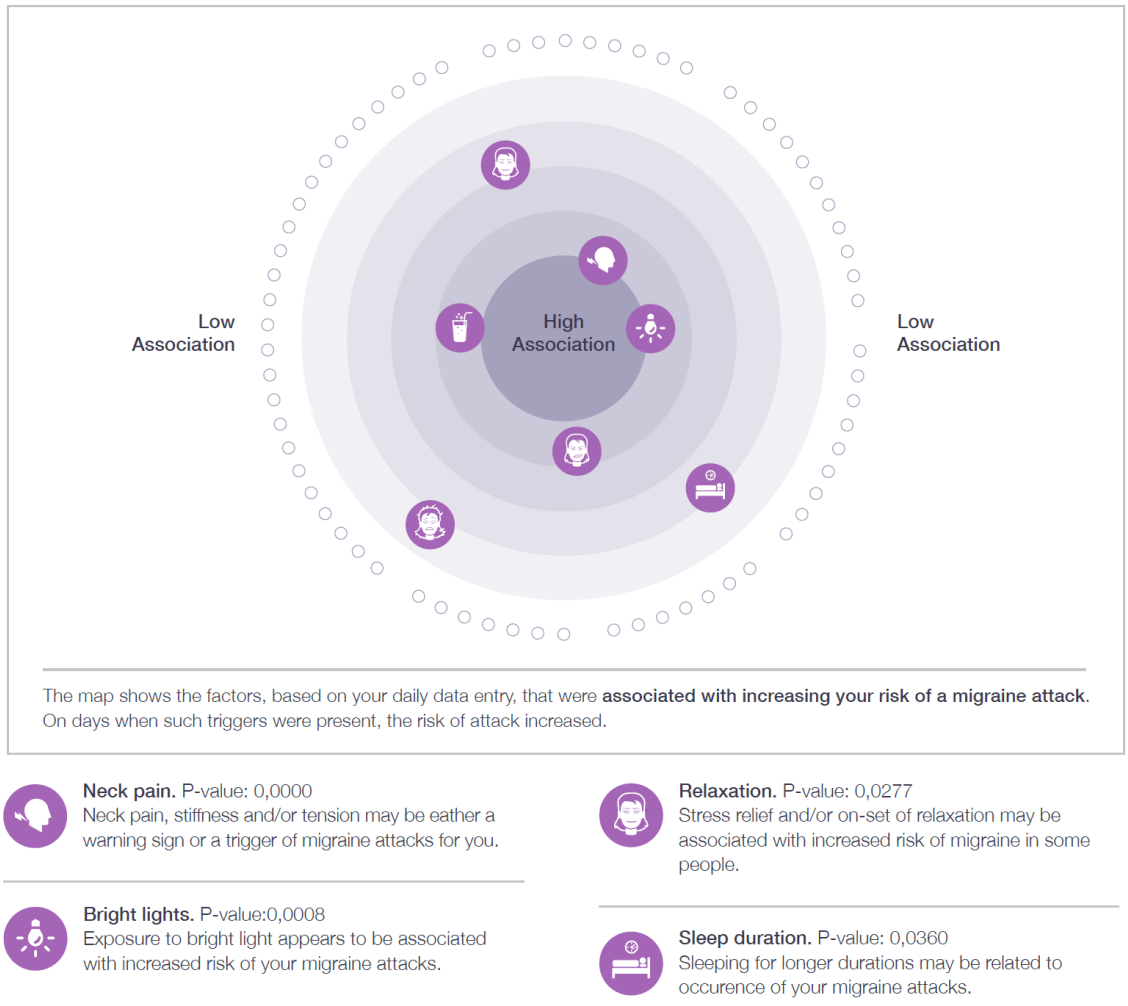


Figure 2.2 "Curelator Headache" Visualization Showing Headache Trigger Associations with Headache Attacks.

"Curelator Headache" has significant improvements over other existing commercial PI applications with respect to in-situ data collection and analysis of collected data to identify potential headache triggers. However, it has several shortcomings as well:

1. The users need to wait at least 45 days to see a visualization of headache trigger association with headache attacks. Headache tracking without reflecting on collected data within this time period may result in reduced adherence in headache tracking.

2. The visualizations are shown in a static report after 45-90 days which do not allow interactive exploration of data for further analysis. For example, the user cannot explore a particular headache day to review all events on that day to generate conjecture about potential headache trigger.
3. P-value [57] is used to indicate the level of association of a headache trigger with a headache attack in the description of the visualization in Figure 2.2. Users might not be familiar with the term "p-value", let alone the significance behind it.
4. The visualization in Figure 2.2 intuitively shows association level of headache triggers with headache attacks without providing details of past occurrences of the triggers (i.e. headaches followed by exposure to bright light versus no headaches followed by exposure to bright light). Details of trigger information may provide a user the opportunity to reflect on collected data to provoke his/her curiosity rather than having a plain insight.
5. The combined effect of multiple headache triggers is not evident from the visualization in Figure 2.2. For example, how much the risk of a headache attack was on a day when both neck pain and exposure to the bright light were present.

I have addressed these issues in the design of the HeadacheTracker application. The visualizations in HeadacheTracker are available as soon as the data is entered by the users. The application also suggests the users to collect more data to have a better estimate of the potential headache triggers. It allows users to review correlation of headache triggers with headaches within different time windows to have a better understanding of how headache triggers evolve over time. The visualizations are interactive to allow exploration of data to leverage data-driven conjectures. Rather than providing p-value statistic, the HeadacheTracker relies on numerical values and

percentages to denote associativity of headache triggers with headache attacks. The combined effects of headache triggers are also shown based on the user selection of headache triggers. The requirements of the HeadacheTracker application are based on user research and are described in detail in Chapter 3.

2.7 Conclusion

In this chapter, the relevant background and existing work are discussed to provide a foundation for a common understanding of the thesis. State of the art of self-monitoring tools for chronic headaches is discussed and improvement areas are identified. It can be inferred from the discussion that tracking and monitoring of chronic headaches are complimentary activities and they have equal importance in achieving self-monitoring objectives. Existing self-monitoring tools do not support the interactive exploration of headache data to identify potential headache triggers as they lack an interactive visual analytics component to relate temporal events to show trends and patterns associating headaches with headache triggers.

Chapter Three: **Requirements Elicitation Study**

In this chapter, I describe requirements elicitation study for the HeadacheTracker application. First, I describe the overall study, its objective, stakeholders, methods, tools and techniques. Second, I describe the results of the study from the perspectives of headache patients. Third, I elicit the requirements for the HeadacheTracker application based on the study results. Finally, I briefly discuss the limitation of the study with concluding remarks. The main learning from the study is that there are different categories of chronic headache patients with diversified needs. The outcome of the requirements elicitation study is a set requirements for the HeadacheTracker's data collection and visual analytic interfaces based on the understanding of the user needs. The design of the HeadacheTracker application focuses on a specific group of headache patients to achieve the research goal.

3.1 Study Description

In this section, I describe how I conducted the study in collaboration with different stakeholders. I also discuss how the participants were recruited, what methods, tools and techniques were used and how the results were obtained by analyzing study data.

3.1.1 Study Objective

The objective of the requirements elicitation study was to understand the self-monitoring needs of headache patients. The outcome of the study is a set of "requirements" that are also the basis of the design of the HeadacheTracker application for headache patients. The elicited requirements are one of the main contributions of this thesis.

3.1.2 Stakeholders

To elicit requirements for the HeadacheTracker application, I chose to work directly with real headache patients to understand their needs. The study was conducted in collaboration with

CHAMP patients and clinicians. CHAMP patients were the main stakeholder of the requirements elicitation study as the HeadacheTracker is supposed to help headache patients to track, analyze and better understand the factors that are influencing their headaches. At the outset of the study, CHAMP clinicians were also consulted to frame the high level needs of headache patients from their point of views.

3.1.3 Observing Headache Education Sessions

For newly registered chronic headache patients at CHAMP, a headache education session is the first point for their learning about diagnosis and treatment of headaches. They also learn about behavioral management of headaches in the same session. I attended a total of 6 headache education sessions as a passive/invisible observer. My main objective of the observation was to find out how the headache patients react when they are introduced to headache diaries for tracking their headaches. In these 6 sessions, I have observed the following things:

1. Most of the headache patients have not tracked headache data before.
2. Some patients have pointed out inconveniences with a using paper diary: not enough space to track things, frequently forgetting the data entry and losing the diary.
3. A few patients have used headache diary applications in the past (e.g. paper diary, mobile app), but are uncertain about what to do with the collected data.

Based on the observations it can be inferred that not only a suitable headache diary for tracking but also the specific knowledge about how headache triggers are correlated with headaches is important for the successful self-management of headaches. A headache diary, in this context, can be useful if it can help a patient to increase his/her knowledge about personal headache triggers.

3.1.4 Participant Recruitment

Using the recruitment poster, email and short project presentation at headache education sessions, a total of 8 unpaid participants were recruited for this study. All of them were registered CHAMP patients who signed a consent form (Appendix A) for participating in the study (REB14-0911). Demographic information of the participants are shown in Table 3.1 (age and gender of participants and participant experience with data collection tool). Of the 8 participants, only 1 was male while the rest were females from different backgrounds. The ages of the participants ranged from 20 to 49 years of age (Table 3.1). All of them were using smartphones for more than 3 years. Table 3.1 shows participants' previous experience with headache data collection tools. Out of the 8 participants, 3 participants (P1, P6 and P7) were totally new to headache data collection. Another 3 participants (P3, P5 and P8) were collecting data using only the CHAMP paper diary. Among these 3 participants, P5 and P8 were collecting headache data for about one month only, so, they were also considered fairly new to data collection. P3 was collecting data for about four months. Others participants (P2 and P4) were collecting headache data using both CHAMP paper diary and commercially available mobile headache applications. P2 was collecting headache data for more than one year whereas P4 was collecting headache data for around ten years. Noticeably, the participants can be divided into three groups:

1. New to headache data collection.
2. Experienced in CHAMP paper diary-based headache data collection.
3. Experienced in both paper and mobile app-based headache data collection.

Table 3.1 Participant Information for the Requirements Elicitation Study

Participant	Age	Sex	CHAMP Diary Experience	Headache App Experience
P1	46	Female	No	No
P2	20	Female	Yes	Yes
P3	34	Female	Yes	No
P4	49	Female	Yes	Yes
P5	35	Female	Yes	No
P6	45	Female	No	No
P7	48	Male	No	No
P8	30	Female	Yes	No

No participants were excluded based on experience, as participants with a wide range of experience were desired, to better represent the wider population that may want to track and analyze headache data. I did not have to recruit more participants because after the 5th participant interview, the answers of the participants started to be repetitive and 8 participants seemed to be sufficient to learn about the self-monitoring needs of headache patients.

3.1.5 Apparatus

I conducted a semi-structured interview study after recruiting the participants to understand their self-monitoring needs with respect to their chronic headache condition. The study was conducted by utilizing the following apparatus:

- Pen and Paper: These were used to engage participants in design discussion, specifically, what kind of analysis they want to perform on their collected data and then how they want to see the information after analysis. I also took notes on paper whenever I felt necessary.
- Audio recorder: The recorder was used to record the whole interview session for further analysis of interview data.

3.1.6 Semi-Structured Interviews

Interviews are widely used tool to access people's experiences and their inner perceptions, attitudes and feelings of reality. Based on the organization of questions, interviews can be structured, semi-structured and unstructured [14]. A structured interview has a set of prearranged questions based on interview objectives and the questions are asked in the same order for all respondents. An unstructured or non-directive interview does not follow prearranged questions (opposite to structured interview). Semi-structured interviews fall between these two approaches. Prior to the semi-structured interview, an interview guide is prepared usually including both close-ended and open-ended questions. But in the course of the interview, the interviewer has a certain amount of freedom to adjust the sequence of the questions to be asked and to add questions based on the participants' responses.

The objective of the interview study in the context of my thesis was to understand self-monitoring needs of the participants. Table 3.2 and Table 3.3 present the interview guide that I have used for the study. Particularly, I wanted to understand the following aspects to answer the Research Question 1:

- What kind of experience do the headache patients have in headache data collection and what are the differences in their data collection approaches?
- Which category of the headache patients will get the most benefits out of data collection and why?
- What are the data collection needs of the target group of headache patients?
    - What are the different data parameters they need to track?
    - What are the types and characteristics of the collected data?

    - What is the frequency of data collection and characteristics of collection approaches?
- What are the needs for instructions and navigational support requirements during data collection?

I also wanted to determine the following aspects to be able to answer Research Question 2:

- How do the headache patients think about headache attack and perceive their headache triggers?
- What are the things the headache patients proactively do or want to do to identify headache triggers?
- What are the needs for different type of analyses (i.e. aggregated analysis, headache day analysis)?
- How is the previous experience and expectation of headache patients with respect to information visualization (i.e. charts showing headache related insights)?

A semi-structured interview is a suitable approach for this purpose as it allows to adjust interview questions based on a participant's response. Based on the insight gained through the literature review and the observation of headache education sessions, I developed a set of interview questions and used the questionnaire as a guide during the actual face-to-face interview sessions. Interviews were conducted at the Calgary South Health Campus and University of Calgary Campus and each session was around half an hour in duration. In the interview session, at first I introduced myself and explained the purpose of the interview session. After collecting participant's informed consent, I started with the question about the chronic headache condition of the participant. Gradually, I moved forward with the interview guide that I prepared earlier and

adjusted or rephrased questions whenever necessary. The predetermined interview questions for the study are shown below in Table 3.2 along with the reason or objective of the question.

Table 3.2 Sample Interview Questions and Objectives

Questions	Objective
How well do you know about the factors that cause your headaches?	To learn about participants' previous experiences, understanding and perceptions about headache triggers.
Do you collect or record data about your headache attacks? How?	To learn if the participant is self-tracking headaches and he/she is then how (i.e. using headache diary).
How do you feel about your current data collection process?	To learn about participants' likings, dislikings and difficulties in current data collection process.
Do you feel that you are collecting enough information about your headaches using the CHAMP headache dairy or do you feel the need for more data collection?	To learn if the participants' are satisfied with data collection parameters available in CHAMP headache diary and if there is a logical need for more data collection.
As you have collected headache data in the past, what did you do with the data? Or, Have you ever tried to make sense of collected data? How?	To learn what kind of analyses the participants' have performed so far based on the collected data.
What challenges did you face when you tried to make sense of your headache data?	To learn about the limitations that participants' had during their analyses.
What things do you want to know from your collected data? Why?	To learn about participants' current need of analyses and reasoning behind the needs.

For the participants' who were totally new to headache data collection, I rephrased few of these questions for them in the following manner (Table 3.3).

Table 3.3 Rephrased Sample Interview Questions and Objectives

Questions	Objective
Do you feel keeping a headache diary would be useful? What benefits do you see?	To understand if participants' are willing to self-track headaches with a belief of potential benefits.
Suppose you have collected data about your headaches and daily activities. For example, you have recorded your sleep, food, drink, exercise, stress etc on a daily basis. You have also recorded your headache episode info such as severity, symptoms, medications etc whenever you have had headaches. What would you do if you have all these data with you? How would you make sense of collected data?	To provoke participants' into thinking about potential ways they can utilize the collected data and to learn what difficulties may arise if they try to make sense of these data.

The interview questions were asked to get a holistic view of the participants' current status and needs with respect to self-monitoring of their headaches. At the end of the interviews, I asked the participants if they have any question for me and concluded the interview session by describing the future plans for development and evaluation of the HeadacheTracker application. All of the participants gave their consent to participate in the evaluation of the HeadacheTracker application. The entire session was recorded using an audio recorder for analyzing transcribed interview data. I also took notes during the interview session which helped me to summarize each interview session when it ended.

3.2 Analyzing the Interview Data

The recorded semi-structured interview sessions were transcribed using a free online audio transcribing tool called "transcribe". The process produced a considerable amount of textual data for analysis in addition to hand written notes. To build concepts from textual data, it is required to analyze the text and summarize the meaning, ideas and thoughts in it. "Open Coding" is a process

for qualitatively analyzing textual content [56]. The open coding method facilitates labeling different concepts and utilize those in developing different themes or categories based on their properties and dimensions. In open coding analysis, important texts are marked and a descriptive name or "code" is given to the marked texts. After having coded texts, the codes are examined closely to find similarities, dissimilarities and common patterns or relations among the codes. Based on the analysis, several categories are formed and similar codes are assigned to a particular category. Sometimes a code alone may not be enough to describe an entire concept. In such a scenario, an explanatory text is written for the particular code which is called a "memo".

I used a free web-based tool called "Saturate" [45] to perform "Open Coding" on the transcribed interview data. The objective was to identify the needs of the participants' in terms of data tracking, data analysis and data visualization. A total of 50 codes were created by reviewing the textual data (Appendix B). All the codes were then categorized based on their conceptual similarities or dissimilarities. The whole process was performed in an iterative manner: creating the codes, refining the codes and categorizing the codes. Based on "Open Coding" analysis different headache patient groups and their needs were identified. Table 3.4 presents the types of headache patients along with their headache characteristics.

Table 3.4 Identified Patient Types with their Headache Characteristics

	New to Data Collection (0 to 1 month)	Experienced in Data Collection (2 months or more)	Total
Headache Attack with Start and End Time	5 (P1, P5, P6, P7, P8)	1 (P3)	**6**
Continuous Headache Pain	0 (No participant)	2 (P2, P4)	**2**
Total	**5**	**3**	**8**

I considered participants, who had no experience to maximum one month of headache data collection experience, as "new to data collection" group (5 participants). Conversely, participants with data collection experience for two or more months were considered as "experienced in data collection" group (3 participants). I also noticed that some participants' (6 participants) had headache start and end times, whereas, others (2 participants) felt headache pain all the time. With respect to the headache data collection experience, I found that most of the participants were new to data collection (either did not start collecting headache data or collected headache data for about one month only). I also found that most of the participants suffering from headache attacks had headaches with a start and end time. All of the participants who were new to data collection were also either unaware or unsure of their own headache triggers. Identifying and understanding how different factors trigger their headaches was one of their biggest motivations behind headache data collection. On the contrary, experienced participants were more knowledgeable about their own headache triggers as they were collecting and analyzing data for some time. Headache patients, experienced in data collection, were more interested in experimenting with their headache triggers as they already have better knowledge about their headache triggers. For example, P4 was collecting headache data for ten years and she knew that doing exercise triggers her headache. She experimented with different kinds of exercises and found that only aerobic exercises trigger her headaches. She described in her own words, *"but if I do anything that raises my heart rate, then I get the headache"*. This means she tracked her heart rate for some time to figure out the pattern that if exercise raises her heart rate, she gets a headache. As the goal of my thesis is to help headache patients understand their headache triggers and headache trends rather than allowing self-experimentation, so, I decided to design the HeadacheTracker application for the particular group who were new to data collection and had headaches with start and end time. The decision is

also based on the fact that collecting and analyzing headache data is particularly useful for those headache patients, whose headache attacks usually occur in response to unidentified triggers [4].

3.2.1 Data Collection Needs of Targeted Group of Headache Patients

Based on headache patient interview analysis, discussions with clinicians and a literature review, I created a list of data parameters that are necessary and important to track for the target group of headache patients. These data parameters can be categorized in the following manner:

- Data parameters related to headache episodes or attacks – headache start and end time, headache severity, disability level, pain location, pain nature, pain symptoms and physical location during onset of headache.
- Data parameters related to headache triggers – food, drink, exercise, sleep, stress, menstruation and weather.
- Data parameters related to headache medications – symptomatic medication, preventive medication.

The CHAMP headache dairy suggests headache patients to record headache severity three times a day (morning, afternoon and evening). Headache patients consider this as an important aspect of data collection, especially the patients who have headache pain all the time or the patients who experience ongoing headache pain for multiple days.

Headache patients have a general perception about their headache triggers but often they are uncertain about what might have caused the headaches. Several headache patients mentioned in the interview that often different foods act as headache triggers for them. For example, P2 said, *"…I find the most helpful thing for me has been trying to keep a food diary because I know foods are kind of big triggers…"*, whereas P4 said, *"…one other most challenging thing I have problems with in identifying triggers is in food, and that is one thing that I haven't been very consistent in*

keeping on paper…". P1 reported too much noise and stress as her headache triggers, P3 said about stress and dehydration being the headache triggers for her. Other headache patients reported red wine, lack of sleep, hormonal changes, and weather as their headache triggers. To know what factors are typically considered as headache triggers, I talked to the headache clinician (neurologist) and got a list of typical headache triggers. The list (data parameters related to headache triggers) of headache triggers is based on a clinical research [3]. There can be other headache triggers beyond this list.

Based on the individual headache condition, headache patients may take symptomatic or preventive medications. Usually, headache patients who have continuous headache pain, take preventive medication. Other patients take symptomatic medications during a headache attack. In each case, headache patients need to track the dose of medication along with its quantity.

Characteristically, all the data parameters patients need to record are timeline based data parameters. For example, a headache patient goes through a series of activities or events at different point of times in a day and one or more of those activities may trigger his/her headache later on. To get rid of headache pain, the patient takes medication while experiencing headache pain. This example implies that everything should be tracked with a timestamp to allow temporal analysis of collected data. The type of the data parameters that are presented at the beginning of this section is that they are discrete or nominal variables. This means that they are categorically different (e.g. food, drink), combined within an interval (e.g. morning, afternoon, 1 week, 1 month) or numerically scaled (e.g. severity level, disability level). When a visual representation of these discrete variables is required, bar graphs and pie charts are two commonly used approaches to represent data as these charts are suitable for showing comparisons and proportions among

categories. These charts are widely used and also relatively easier to understand by users with less or no experience with charts.

A very important aspect of the self-tracking of the headache data is to understand the contextual needs of the headache patients with respect to data collection. All of the interview participants acknowledged the need and importance of tracking in-situ data. They preferred mobile technology over other means simply because they always carry mobile phones with them and want to track things as they happen. Two participants (P6, P8) reported that they collect headache data once in a day and usually at night when they go to sleep. The reason behind this is the paper-based dairy they use to track headache data. It was inconvenient for them to always carry the paper diary with them as they feared to lose it somewhere. They also reported that a mobile headache diary would allow them for in-situ data collection.

While talking about using a mobile application for tracking in-situ data, P1 said, *"...cell phones are not allowed during work time but I can remember things till I finish my work and record it later in the application. A notification or reminder from the app can be useful in such context..."*. P2 discussed ease of use, *"...definitely there is this challenge of not quiet understanding how it works when there is something that technical, I know for me, because I know I am not very technically advanced..."*. This suggests the need for different kinds of assistive instructions during navigation through different pages of the application and reminder notifications for recording data retrospectively. P3 said, *"I wouldn't want anything that is going to take me more than a minute or 2 to fill out because I won't use that..."*, which suggests the need of interaction flow design for quick data entry. Other participants also made similar comments when they were asked about the challenges of using a mobile-based headache dairy application.

3.2.2 Exploratory Data Analysis Needs of the Target Group of Headache Patients

Based on the interview data analysis, I found that headache patients showed interest in three categories of data analysis:

1. Analyzing headache data of a particular day – short term analysis.
2. Analyzing correlation of a trigger factor with the frequency of headaches – long term analysis.
3. Analyzing common patterns of headache attacks – headache trend/pattern analysis.

Often headache patients are uncertain about their triggers during the onset of headaches. I found that headache patients who are new to data collection are either unsure or unaware of their headache triggers. In most cases, they use their guesswork or speculation to identify their headache triggers. In the interviews, headache participants expressed their interests to track activities or events as they happen and upon headache onset they want to review those tracked events or activities to generate data-driven conjectures about headache triggers based on temporal events on that particular headache day. In the interview discussion, P1 said, "…*So it would be useful to track things and then whenever headache starts I can come back and see what I just did or had just before the headache…".* Similarly P8, P7 and P6 also wanted to see temporal events before headache onset to identify probable headache triggers. In her own words, P6 said, *"…I would also like to see correlations between the factors, for example, if I have lack of sleep last night and then I am doing a stressful work, I would like to know how these factors triggered my headache…".*

Headache patients were also interested in long term analysis – analyzing to what extent a headache trigger is responsible for headaches and also how a combination of headache triggers increase the possibility of having a headache. All of the participants in the interview wanted to

know the impact of a trigger factor in the long term but were unsure how to analyze the collected data. For example, P5 said, *"…For me, I will probably, may be just have like, weather and stress levels to correlate with my headache frequency…"*. This statement asserts the intention of analyzing the data over a long term but P5 was unsure how she wants to view this information. I found, as expected, that most of the participants were not educated in statistical analysis. In addition, participants wanted to view insights using simple graphs. While talking about extracting insight out of collected data, P7 said, *"…I can use different charts or graphs. But I am only familiar with bar graph or line graph and anything other than that I may not be able to understand…"*.

The last kind of analysis headache patients wanted to perform is the aggregated view of headaches. For example, P8 said, *"…From this data, I would like to know my symptoms, how frequently they happened and where I was when it happened and then environment condition, medications etc…"*. In fact, most of the participants wanted to know these kind of aggregated information such as when the headache usually started in the day, average pain severity and disability, what were the symptoms, most frequent pain locations and the physical locations during the onset of headaches. These were important insight for them as the patients need to share these insights with the clinician for diagnosis and treatment.

3.3 The HeadacheTracker Requirements based on Interview Analysis

Based on the needs elicited from the interview discussions, I came up with the following requirements that the HeadacheTracker application needs to meet to be a useful application for headache patients. I define these criteria as high level "requirements" that govern the design of the HeadacheTracker application.

1. HeadacheTracker application must be accessible from a portable handheld device (i.e. smartphones) as headache patients were interested in in-situ data collection.

2. HeadacheTracker application must be accessible from different platforms of handheld devices (i.e. iOS, Android) as headache patients who participated in the study had different platforms (60% iOS and 40% Android).
3. HeadacheTracker should have a mechanism for temporal data collection that supports both in-situ and retrospective data collection.
    a. In case of in-situ data collection, the application should remember the specific screen or page of the application where a user was last time so that the user can resume data entry from that specific screen or page.
    b. In case of retrospective data collection, the application should allow users to specify the time of tracking a data parameter.
    c. At the end of a headache entry, there should be a summary page of all the entered data parameters so that users can review and update or discard any data parameter before confirmation. This is to enable users to avoid the entry of any erroneous data parameter. The summary page should also have an option to delete the entire headache entry if required.
    d. There should be support for the tracking of user-defined data parameter to allow maximum flexibility in tracking headache and trigger related data. For example, if a user wants to track a food item that is not available in the preloaded list of food items, the user should be able to record the food item as a new food item.
    e. There should be a free-form text input to allow users to enter ad-hoc information.

4. HeadacheTracker should allow multiple entries for headache severity within a single day and day wise tracking of headache severity and disability levels in case a headache is spanned across multiple days. This is to allow users record changes in headache severity and disability levels within one headache period.
5. HeadacheTracker should have relevant contextual instructions on each page for helping the users with data tracking and with navigating through the pages.
6. HeadacheTracker should track weather data automatically facilitating data analysis to find if changes in weather have an impact on headache attacks.
7. HeadacheTracker should allow users to move between data entry interfaces and data visualization interfaces easily.
8. HeadacheTracker should allow users to interact with the collected data and explore insights by providing the following types of visualizations:
    a. Visualizations showing aggregated record of different parameters related to headaches based on collected data. For example, average severity or disability levels, distributions of pain on different location of head, distribution of physical locations during onset of headaches, distribution of headache symptoms, and distribution of headache start times.
    b. A visualization showing headache days and headache free days and when a headache day is selected, another visualization should show recorded events on a headache day based on collected data.
    c. A visualization suggesting potential correlation of a self-tracked headache trigger with the onset of headaches and also impact of combined headache triggers on the frequency of headaches based on collected data.

9. Visualization charts in the HeadacheTracker application should be easy to understand by novice users who do not have advanced knowledge of using and interpreting visual charts. Bar chart, pie chart and line chart are suitable options for the HeadacheTracker application given the types of data and user needs.

3.4 Study Limitations

Each interview was scheduled for 30 minutes. Some interview discussions were more than 45 minutes. I felt that if I could spend more time in the interview session, I could gather more direct and meaningful information from the participants. But due to time constraint of participants, I could not do a more elaborated interview study. Also, most of the participants were not familiar with data analysis to find pattern and insight which I felt restricted them to engage or describe their needs more clearly.

3.5 Chapter Summary

In this chapter, I describe the overall requirements elicitation study based on which I developed a set of requirements to govern the design of the HeadacheTracker application. I also explain which tools and techniques I have used to perform the study and how the analysis is performed to elicit the requirements. The HeadacheTracker application is designed based on the elicited requirements from the study.

Chapter Four: **Design and Development of the HeadacheTracker**

HeadacheTracker is a smartphone-based personal informatics application for self-monitoring of headaches. In Chapter 3, I described the requirements of the HeadacheTracker application for data collection and data analysis scenarios. In this chapter, I apply these requirements to design and develop a functional prototype of the HeadacheTracker application.

In Section 4.1, I briefly describe the overall approach I took to design and develop HeadacheTracker application and provide a rationale for my approach.

In Section 4.2, I describe how I translated the requirements into low-fidelity prototypes of the HeadacheTracker. I created multiple user interface alternatives and compared them with each other to iteratively design the HeadacheTracker user interfaces that reflect the user requirements.

Once I had the final low-fidelity prototypes ready, I started development of the HeadacheTracker application. I discuss the pre-development considerations and system architecture in Section 4.3.

In Section 4.4, I present the HeadacheTracker application to describe its overall design and explain how the application helps headache patients. I also provide a comparison of the HeadacheTracker with existing applications for self-monitoring of chronic headaches.

Figure 4.1 HeadacheTracker Application Design and Development Approach

4.1 Approach

I adopted the approach, shown in Figure 4.1, for design and development of the HeadacheTracker application. The requirements elicitation study is already discussed in the last

chapter. Although, the development process may look like a waterfall software development model, the HeadacheTracker development process involved iterative loops between the various stages. For instance, in low-fidelity prototyping, I created multiple user interface alternatives, compared them with each other and modified them to improve usability of the interfaces. I also developed the user interfaces in an iterative manner by developing data collection interfaces based on low-fidelity prototypes, showing them to the users and incorporating their feedback in the design of data collection user interfaces.

After eliciting user requirements, I used low-fidelity prototyping to quickly convert the requirements into tangible design artifacts. Prototyping is useful for creating experimental designs to explore design alternatives. Prototypes can be developed quickly to depict concepts and ideas at a low cost [38]. An abstract idea or concept often needs interpretation but a prototype is an observable and tangible artifact [5]. The main objective of prototyping is to involve users in the early stage of development to get their feedback to identify improvement areas. This reduces the time and cost required for the development process, because it facilitates an iterative design process where user interfaces can be improved by involving users in the discussion, exploration and testing of prototypes [44]. Usually, the designer facilitates a discussion session involving the users by demonstrating the prototypes to them [41]. In the context of my thesis, I chose to develop low-fidelity prototypes where I used an iPad with hand-drawn interface elements to mock-up interface layouts. This is a cheap way of testing design alternatives in participatory design sessions. The main focus of low-fidelity prototyping was to quickly construct artifacts to depict concepts and user interface layouts, instead of modeling the user interaction with an interface. Low-fidelity prototypes show the general look and the feel of the interface just enough to get the interface evaluated by prospective users by communicating and exchanging ideas with them. The

prototyping approach served well in the specific context of the HeadacheTracker application development where requirements were fairly high level. Low-fidelity prototyping allowed me to create quick mock-ups for the HeadacheTracker to explore different user interface alternatives and iteratively improve the prototypes by addressing relevant user requirements. I describe the low-fidelity prototyping of the HeadacheTracker in detail in Section 4.2 of this chapter.

After creating the low-fidelity prototypes, I started development of different features, functionalities and user interfaces of the HeadacheTracker application. During the development of data collection user interfaces, I arranged a walkthrough of the interfaces with two headache patients and a CHAMP headache doctor (neurologist) to receive their feedback on the design. I asked them, for example, to create a headache entry and let me know if they had any issue or ideas for improvement. More specifically, I did this to understand their perceptions of the effectiveness or usefulness of the data collection interfaces. It also allowed me to capture early user feedback in the development lifecycle to make sure that I was adequately addressing the user requirements during the development of the HeadacheTracker application.

4.2 Low-Fidelity Prototyping of HeadacheTracker

I categorized the elicited requirements for two major objectives: requirements for data collection interfaces and requirements for data visualization interfaces. Three data collection interfaces were needed to be developed as I outlined in the last chapter:

1. A user interface for recording a headache attack.
2. A user interface for tracking potential headache triggers.
3. A user interface for tracking medications.

There were also three data visualization interfaces needed to be developed:

1. An interface for showing visual representations of aggregated headache parameters.
2. An interface for showing recorded events separated by time segments (i.e. morning, afternoon, evening and night) on a headache day to identify potential headache trigger.
3. A visual analytic interface for showing possible correlation of headache triggers with headaches and allowing users to review the correlations for multiple time windows.

My basic objective was to create multiple low-fidelity prototypes for each of these interfaces to compare and choose the best ones from them that meet the user requirements. I created multiple prototypes [58] of the same interface to make the high level user requirements more concrete and analyze the possible problems based on the usage scenarios of the interfaces. I analyzed pros and cons of multiple low-fidelity prototypes of each interface to refine and improve them iteratively. In addition to my own analysis of the low-fidelity prototypes, I also evaluated them with two researchers, Dr. Anthony Tang (researcher in personal informatics and human-computer interaction) and Dr. Frank Maurer (researcher in software engineering). To do a quick evaluation, I went with cognitive walkthrough [11] by the researchers to identify problems and improvement areas for the low-fidelity prototypes. I got frequent feedback from these two researchers over a period of multiple sessions and improved the user interface layouts based on their feedback.

The main differences among the multiple sets of low-fidelity prototypes were in the information organization, interaction and navigational approaches. I designed the low-fidelity prototypes for data collection interfaces first, since the design of visual analytic interfaces largely

depends on how and what data is being collected by the user. After working out the low-fidelity prototypes for data collection interfaces, I started creating data visualization user interfaces in the same manner. Below, I provide two examples of low-fidelity prototypes to demonstrate how elicited user requirements were reflected in the prototyping process (Appendix D shows all the low-fidelity prototypes). Figure 4.2 and Figure 4.3 show two of the prototypes to create a headache entry. Interaction sequences are shown by an orange colored return sign on each page. In Figure 4.2, the home screen had two options: track and analyze. User needed to tap on "track" to go to the next page where headache tracking, trigger tracking and medication tracking options were available. Headache entry was allowed for today, yesterday and the day before yesterday only. Headache start time was defined as morning, afternoon or evening without any specific time. This was done to keep similarity with paper-based headache diary recommended by CHAMP (Figure 1.1). In case of the low-fidelity prototype shown in Figure 4.3, the home screen had four options: headaches, activities, medications and analyze. The home screen also contained a contextual message about headache and instruction for creating a new headache entry. In contrast to the previous one, this prototype had a different approach by allowing users to specify or adjust the headache start and end time for either in-situ or retrospective entry. It also had option for severity tracking at different times of a day as per user need.

During the evaluation of the prototype shown in Figure 4.2, it was pointed out that it cannot support the requirement of retrospective data collection since the user is not allowed to set the headache start date and time according to his/her need. In addition, if no specific start time is recorded then it won't be possible to do a temporal analysis to figure out how headache triggers influence the onset of headaches. The other prototype in Figure 4.3 was better from these perspectives and was chosen over the prototype in Figure 4.2.

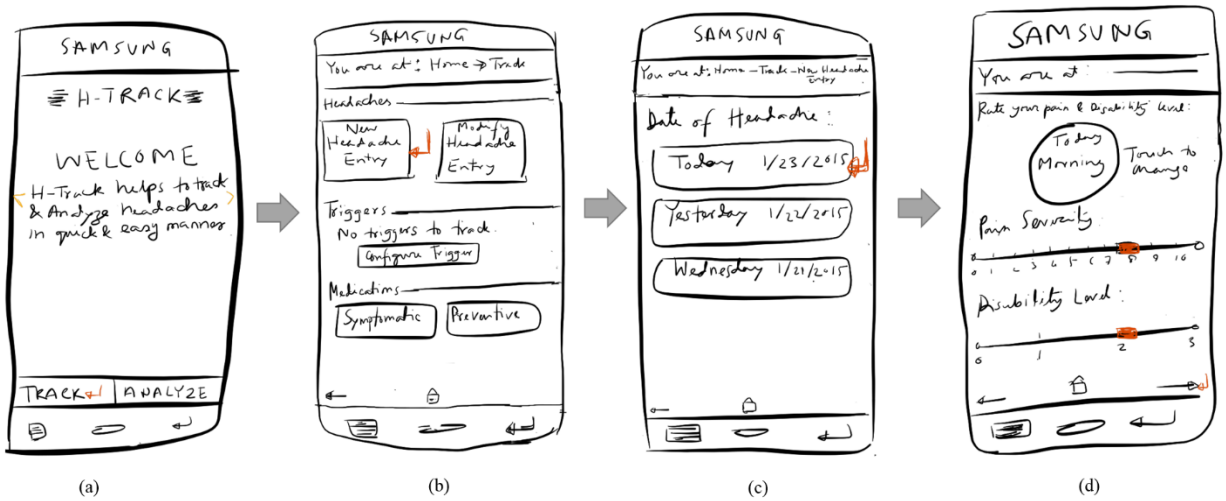


Figure 4.2 Low-fidelity Prototypes for Headache Entry without Specific Time

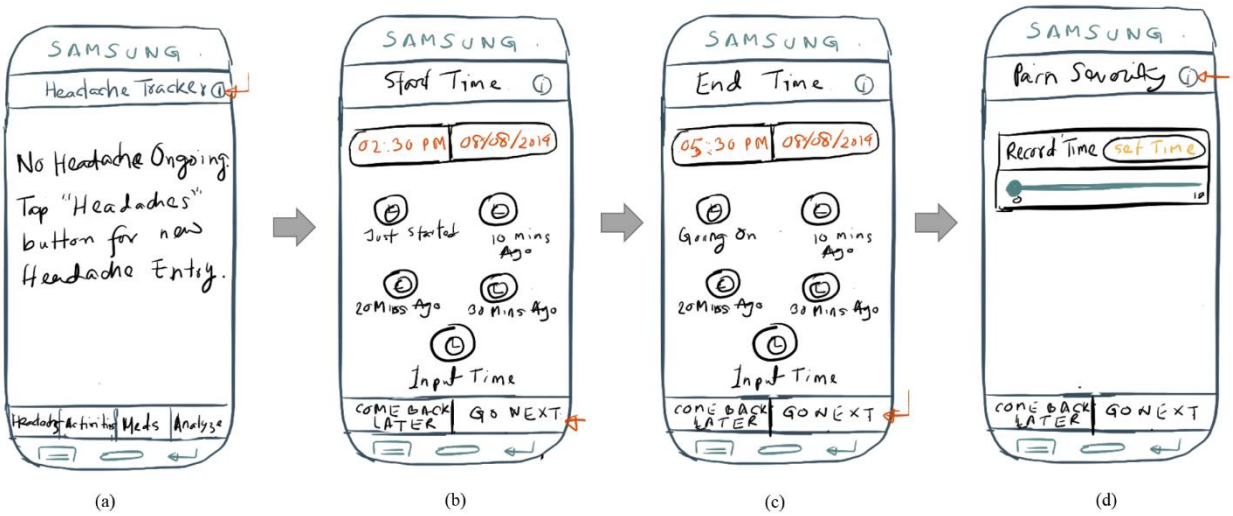


Figure 4.3 Low-fidelity Prototypes for Headache Entry with Specific Time

Figure 4.4 and 4.5 show two low-fidelity prototypes to meet the requirement of short term headache trigger analysis where headache patients are curious about what went wrong on a particular day by going through series of events or activities to identify probable triggers. The low-fidelity prototype shown in Figure 4.4 had parallel timelines where different events or activities

were shown across timelines to provide an idea about what happened before the onset of a headache. In the other prototype in Figure 4.5, instead of parallel timelines, first a calendar view was shown where user can select a particular headache day. The users then could review all the events in sequential manner separated by different segments of the day.

During the evaluation of the prototypes shown is Figure 4.4 and 4.5, it was pointed out that headache patients may find it difficult to understand how to interpret the parallel timelines. This might restrict their ability to understand probable headache triggers. The other prototype was better as it provided a high level view of all headache days and allowed to review all events or activities of a headache day in a more readable and thus understandable form.

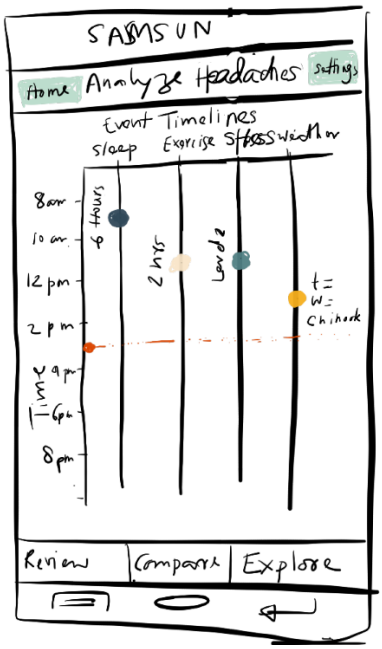
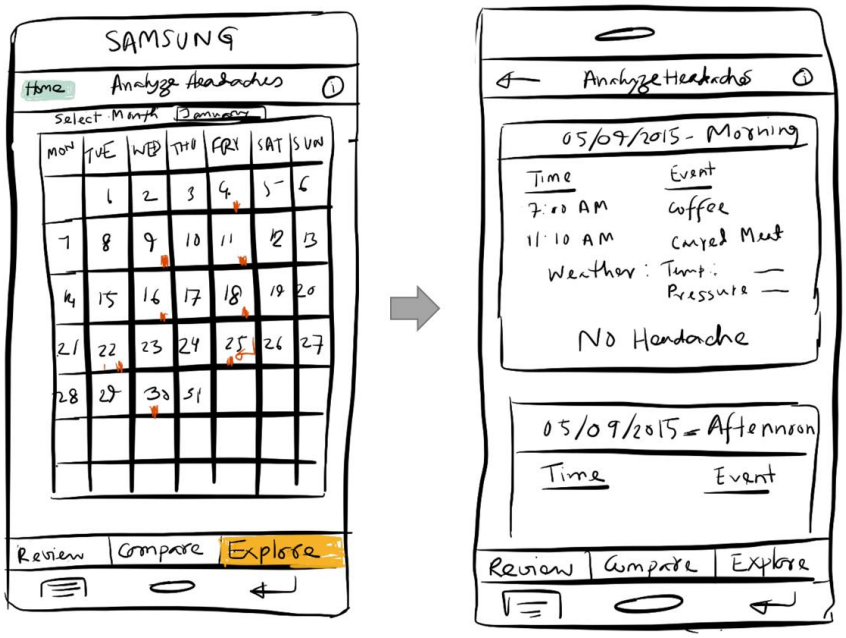


Figure 4.4 Low-fidelity Prototype Showing Events on Parallel Timelines



(a) (b)

Figure 4.5 Low-fidelity Prototype Showing (a) Calendar View and (b) Daily Events

4.3 Development of HeadacheTracker

4.3.1 Technology Decisions

The first major decision point for the development of HeadacheTracker was to decide if a native application or a mobile web application should be developed. Based on the interview study, I found that headache patients use multiple platforms (e.g. iOS, Android). Developing a native application means excluding substantial number interested participants and making user recruitment restricted to a single platform. In addition, a few participants suggested that it might be useful to be able to access the application using a desktop if required, for example, to review the charts or graphs on a bigger screen. So, I decided to develop a mobile web application considering all these factors.

Before starting the development of the HeadacheTracker mobile web application, I had to decide on the client-side and server-side technologies. I searched for a suitable mobile web library

that is optimized for mobile development. I chose jQuery Mobile for this purpose, which is built on top of jQuery. This means jQuery Mobile comes with all the benefits that jQuery has (e.g. easier Document Object Model manipulation). Actually, jQuery Mobile is a HTML5-based user interface system designed to make responsive applications that are accessible on all smartphone, tablet and desktop devices. I also used JavaScript for client side functionalities along with jQuery Mobile. With the client-side decisions of mobile web application using jQuery Mobile made, I considered several alternatives for server-side technologies as well. Finally, I chose node.js for server-side technology. One of the key benefits of node.js is that the code developers write on the server side is written in JavaScript, just as the client side code. To utilize the benefit of the jQuery Mobile and node.js combination, I searched for a database that works well with them. MongoDB is one such option due to the fact that it works well with JavaScript, and therefore node.js. MongoDB stores data (i.e. documents) as an object represented with JSON, which of course is native to JavaScript. Since MongoDB does not store data in relational form (i.e. tables, rows), it allows flexibility to add or modify "document" data object easily. This is particularly useful since in HeadacheTracker there was a need to record user-defined data parameters in an ad-hoc manner. To make life easier, I also used Mongoose which is a simplified object-modeling framework that abstracts away complexities of working with MongoDB from node.js code.

The last decision I had to take is about client-server communication. For this purpose, I used a RESTful web API. Representational State Transfer (REST) is a set of principles that when combined describe how common standards, HTTP specifically, can be used to define a remote system interface in a client-server system. As the client-side is based on jQuery, I used jQuery Ajax call to the REST service for HeadacheTracker application.

4.3.2 HeadacheTracker's Architecture

Figure 4.6 shows the end-to-end RESTful communication architecture based on the technology decisions discussed above. A user loads the HeadacheTracker application on any mobile platform and is able to create, read, update and delete data using the REST API calls.

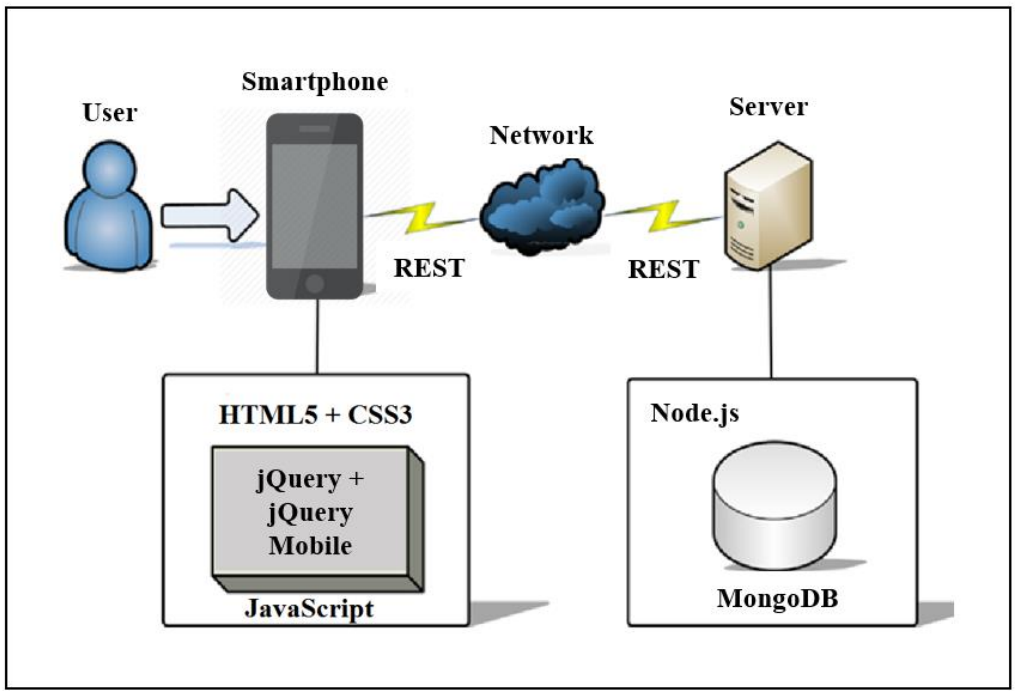


Figure 4.6 HeadacheTracker RESTful Communication Architecture

The HeadacheTracker application architecture is based on the Model-View-Controller (MVC) design pattern [20]. In an MVC design pattern (Figure 4.7), the users interact with the view which presents data to the user using any supported format and layout. The controller acts as a proxy between the view and the model, receives user requests and calls appropriate resources to carry them out. Finally, the model receives requests from the controller and then replies to those requests based on data and business logic.

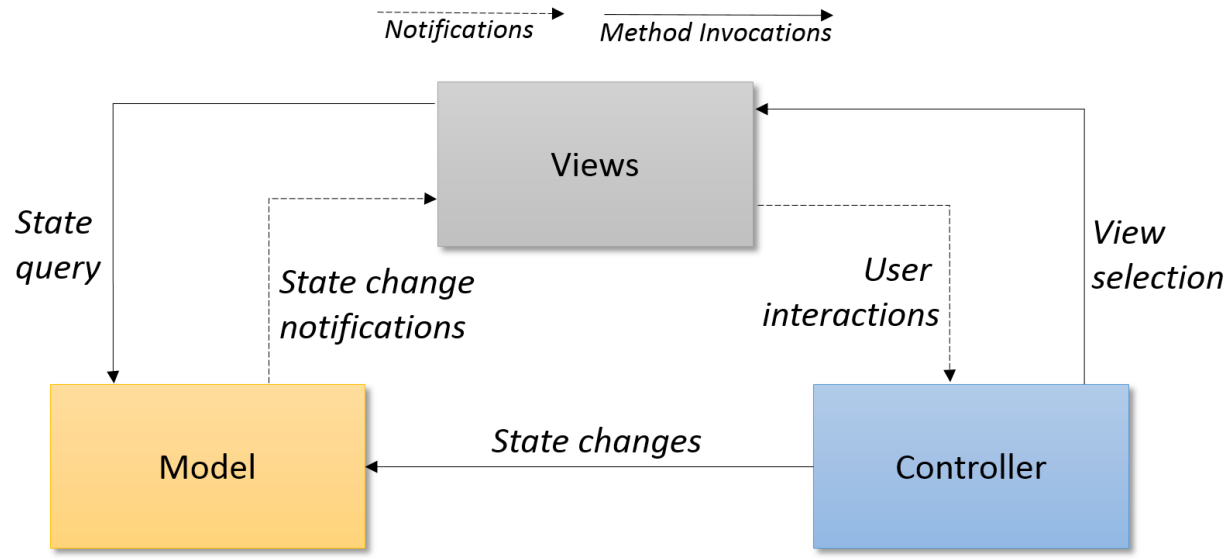


Figure 4.7 Model-View-Controller Design Pattern (source: [62])

In the context of the HeadacheTracker application, the view consists of several jQuery Mobile pages with options for tracking headaches, activities or events, medications and visualizations. The views had a main controller that delegates works to other controllers to handle interactions separately. For example, there are separate controllers for headache entry, activity entry, medication entry and creating visualizations of data. The controllers are responsible for communicating with the models to generate appropriate results for the views.

4.3.3 Database (Model)

Based on the requirements for the HeadacheTracker Application, I kept the database structure fairly simple. As I mentioned earlier, I used MongoDB as a database. MongoDB is an open source document-based NoSQL database implementation. In the context of the HeadacheTracker application, MongoDB provided a number of benefits:

- Documents stored in MongoDB map nicely to programming language data types, specifically those found in JavaScript, making them easy to work with.

- A document itself can have other documents, or arrays of documents, embedded within it, which reduces the need for joins, as developers would have in a relational database.
- The fact that there is no well-defined schema to which documents must adhere means that MongoDB makes polymorphic behavior easy to achieve.

Using Mongoose as a data object modeling framework, I created several schemas for the HeadacheTracker application. For example, the following schema is used for headache entry.

```
headache : mongoose.Schema({
    userID : "string",
    headacheID : "string",
    startTime : "string",
    startTimeAMPM : "string",
    startDate : "string",
    endTime : "string",
    endTimeAMPM : "string",
    endDate : "string",
    severity : [{recordTime : "string", recordTimeAMPM : "string", recordDate : "string", severityLevel : "number"}],
    disability : {recordDate : "string", disabilityLevel : "number"},
    painArea : {tmj : "boolean", sinus : "boolean", cluster : "boolean", tension : "boolean", migraine : "boolean", neck : "boolean"},
    painNature : "string",
    painSymptom : {noSymptom:"boolean", lightSensitivity : "boolean", soundSensitivity: "boolean", nasalCongestion : "boolean",
        nauseaCondition:"boolean", depressedMood:"boolean", smellSensitivity:"boolean", feelAnxious:"boolean", otherSymptom:"boolean"},
    userLocation : "string",
    painNote : "string",
    lastSaved : "string",
    confirmed : "boolean"

}),
```

Figure 4.8 Data Model for Creating a Headache Entry

There are schemas for food, drink, exercise, sleep, stress, menstruation, medication, weather and timebucket. The timebucket schema is created to define time segments of the day. The time segments are morning, afternoon, evening and night. Each data entry activity falls within any of these time segments. The timebucket schema is updated for each data entry activity performed by the user. The schema is used for creating the visualization depicted in Figure 4.5(b). All of these schemas are included in Appendix C.

4.4 Description of HeadacheTracker User Interfaces

As I mentioned in Section 4.2, HeadacheTracker consists of data collection interfaces and data analysis/visualization interfaces. In this section, I provide a brief description of the interfaces and explain how it is designed to help headache patients to track and analyze headache data.

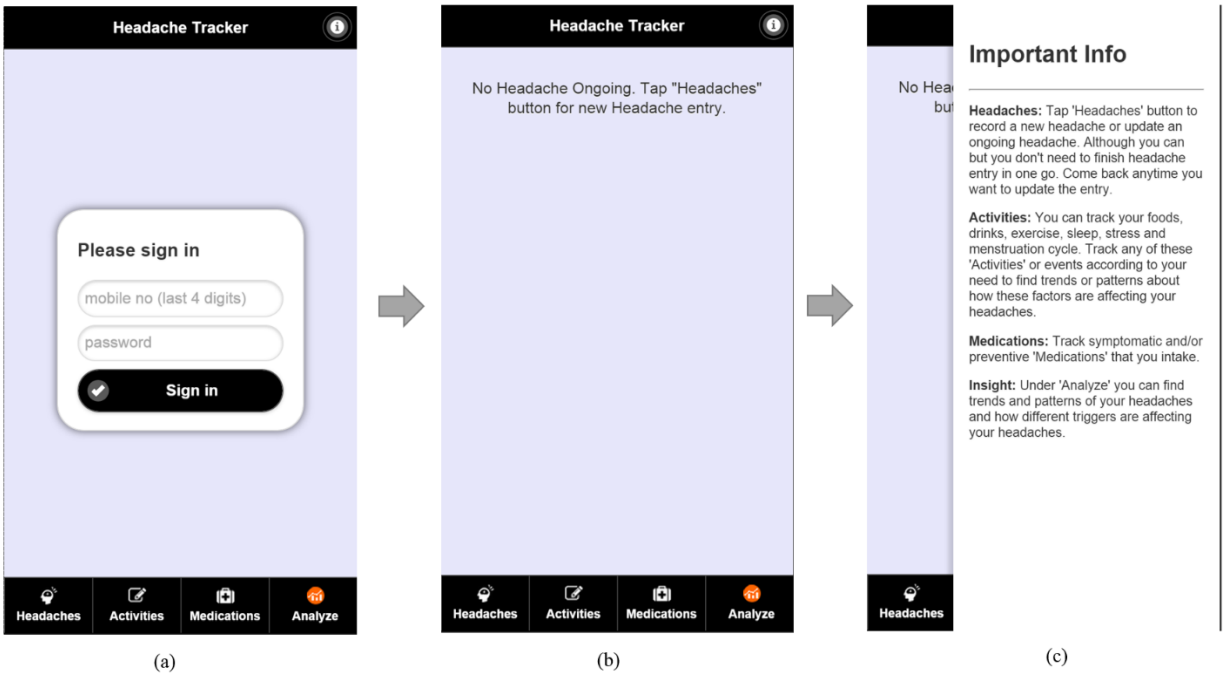


Figure 4.9 (a) Login Screen, (b) Home Screen and (c) Info Panel

The home screen of HeadacheTracker application is shown in Figure 4.9. There is a simple login screen (Figure 4.9(a)) that provides secured data entry for headache patients. Links for all three different kinds of data collection interfaces are available in the home screen to allow quick access to any data collection activity. The home screen also has a link to the analytical interfaces. The home screen shows the current headache status of the user (Figure 4.9(b)). On each page there is an “info” link on the top right corner which brings out a right side panel (Figure 4.9(c)) that

shows contextual information and helps users find the required information. Figure 4.10 shows a basic user interface flow diagram for the HeadacheTracker application.

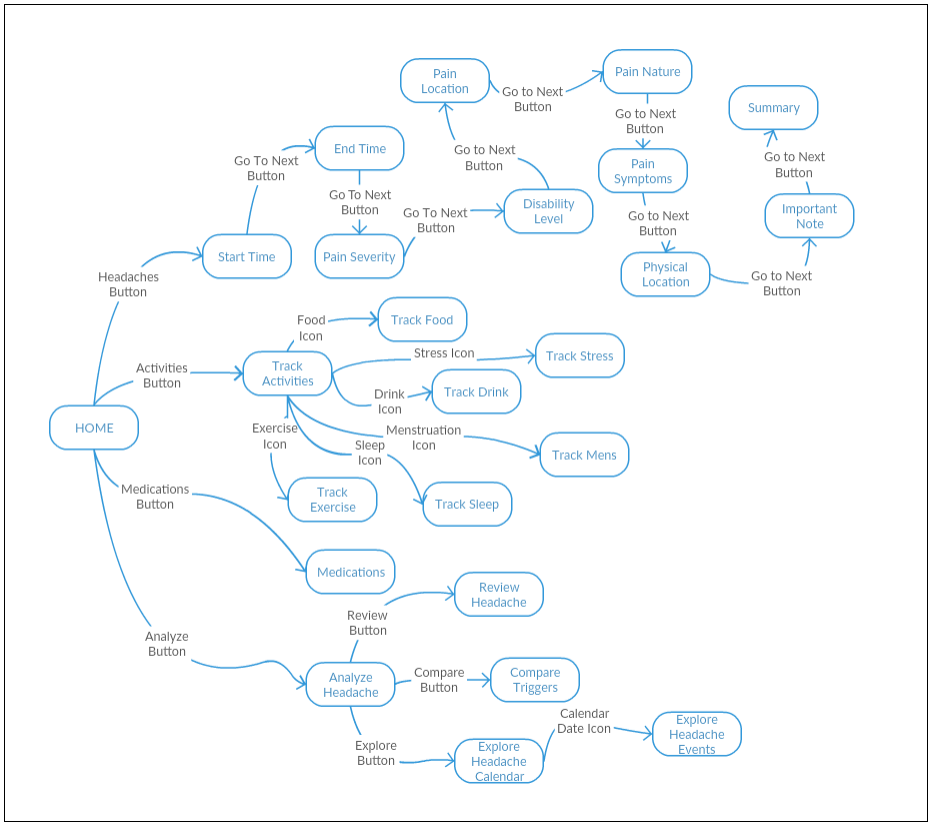


Figure 4.10 HeadacheTracker User Interface Flow Diagram

4.4.1 Data Collection Interfaces

A common feature of most of the data collection interfaces is an on-screen date and time selector to record the data tracking time. The basic requirement was to support data collection for both in-situ and retrospective data entry. Here, I describe the user interfaces for headache entry, activity/event entry and medication entry.

4.4.1.1 Headache Entry

Figure 4.11 shows the interfaces to specify headache start time. Based on the interview data analysis and the CHAMP headache dairy, I decided the required data parameters for a headache entry. One of the requirements was to support temporal data collection for both in-situ and retrospective data entry. The requirement is addressed in the headache entry interfaces by showing an on-screen adjustable date and time component. Also the users are allowed to exit the application anytime during the data entry and come back later based on needs. The application saves the data entry activity on each page and remembers the last page the user was interacting with to help him/her start again form the page where he/she had left. For example, at the onset of a headache, a user can create a headache entry by tapping the "Headaches" button in the home screen, set the headache start time (Figure 4.11(c)) and tap the "Come Back Later" button to save the entry and come back later. When the user comes back to update the headache entry, the home screen shows an appropriate message (Figure 4.12(a)) to guide the user. When the user taps "Headaches" button to update the headache entry, the headache start time page shows the last saved headache start time data (Figure 4.12(b)). Figure 4.12 shows how the user proceeds further in the context.

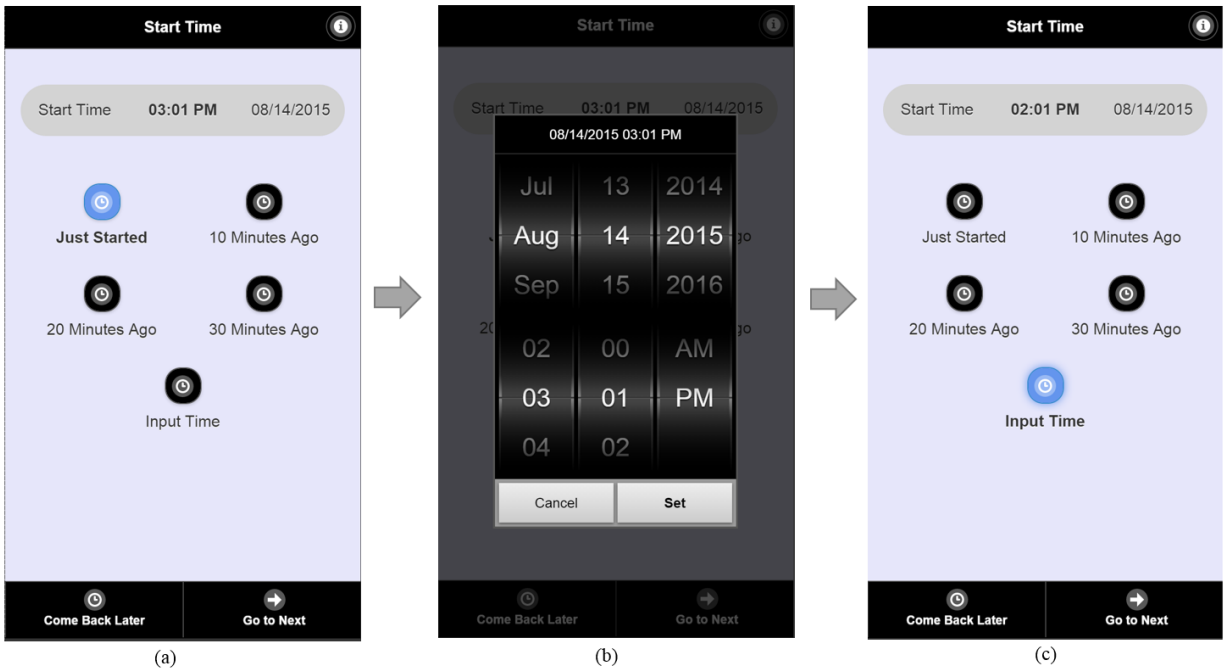


Figure 4.11 (a) Default Start Time (b) Adjust Date and Time and (c) Adjusted Date and Time

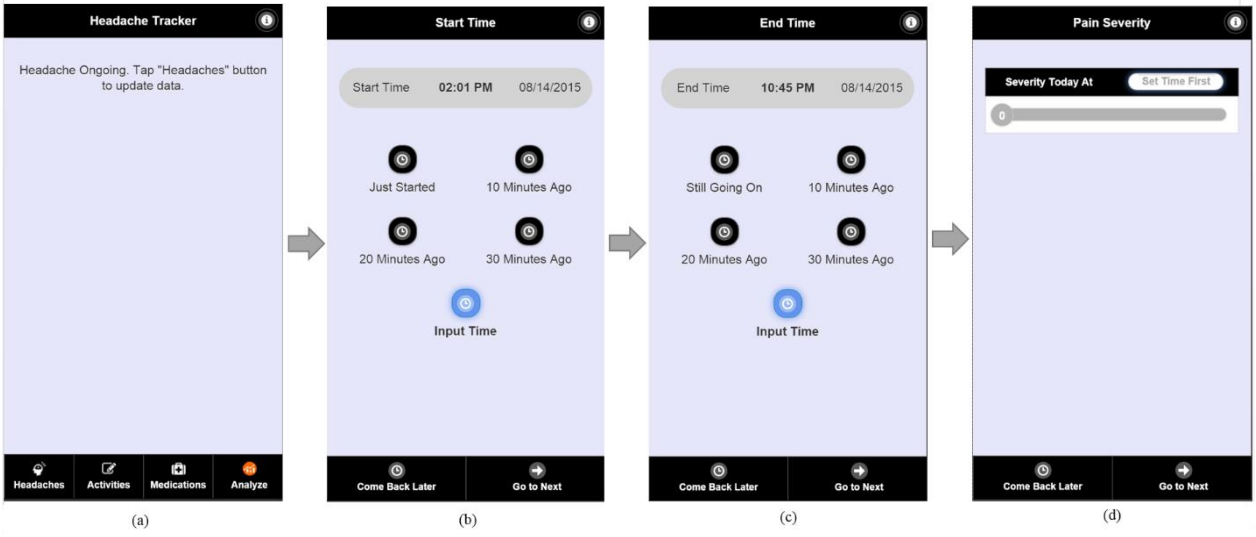


Figure 4.12 (a) Home Screen Message, (b) Saved Start Time Screen, (c) End Time User Input and (d) Headache Severity Screen

Another user requirement for the HeadacheTracker application was to support multiple headache severity entries if required within a single day. The user sees the headache severity screen (Figure 4.12(d)) when he/she proceeds with the headache entry. The user needs to set the tracking time first to activate the severity level slider (Figure 4.13(a)) and then the user can set the headache severity level as per need (Figure 4.13(b)). The user may wish to come back later to update the headache entry if the headache is ongoing. When the user comes back to the headache severity screen again for an ongoing headache, it shows another headache severity slider (Figure 4.13(c)) in addition to the previously recorded severity and thus satisfies the user requirement of multiple severity entries. The HeadahceTracker application allows three severity entries for each day similar to the CHAMP headache diary with the difference that HeadacheTracker allows to record the severity time as well for each severity entry. Figure 4.13 shows the headache severity screens. When the user taps the "Set Time First" textbox shown in Figure 4.13(c), the same clock shown in Figure 4.13(a) pops up for the user to set severity tracking time. Figure 4.14 shows contextual message and instructions available for the users on severity page.

Figure 4.13 (a) Severity Tracking Clock, (b) Severity Level, (c) Second Severity Input for the Same Headache and (d) Second Severity Time with Severity Level

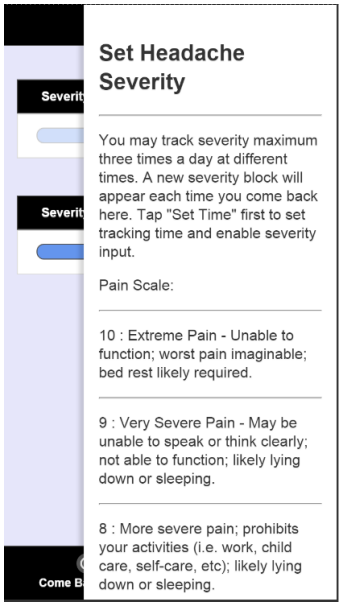


Figure 4.14 Headache Severity Instruction and Severity Level Information

Other headache parameters to complete a headache entry are headache disability, headache pain location, pain nature, pain symptoms, physical location of user and adding a note. Figure 4.15 shows all these sequentially. The user can skip pain location, pain nature, pain symptoms, physical location and important note screens without entering data if required. The mandatory data parameters for a headache entry are headache start time, headache end time, pain severity and pain disability as these were required parameters by CHAMP headache diary.

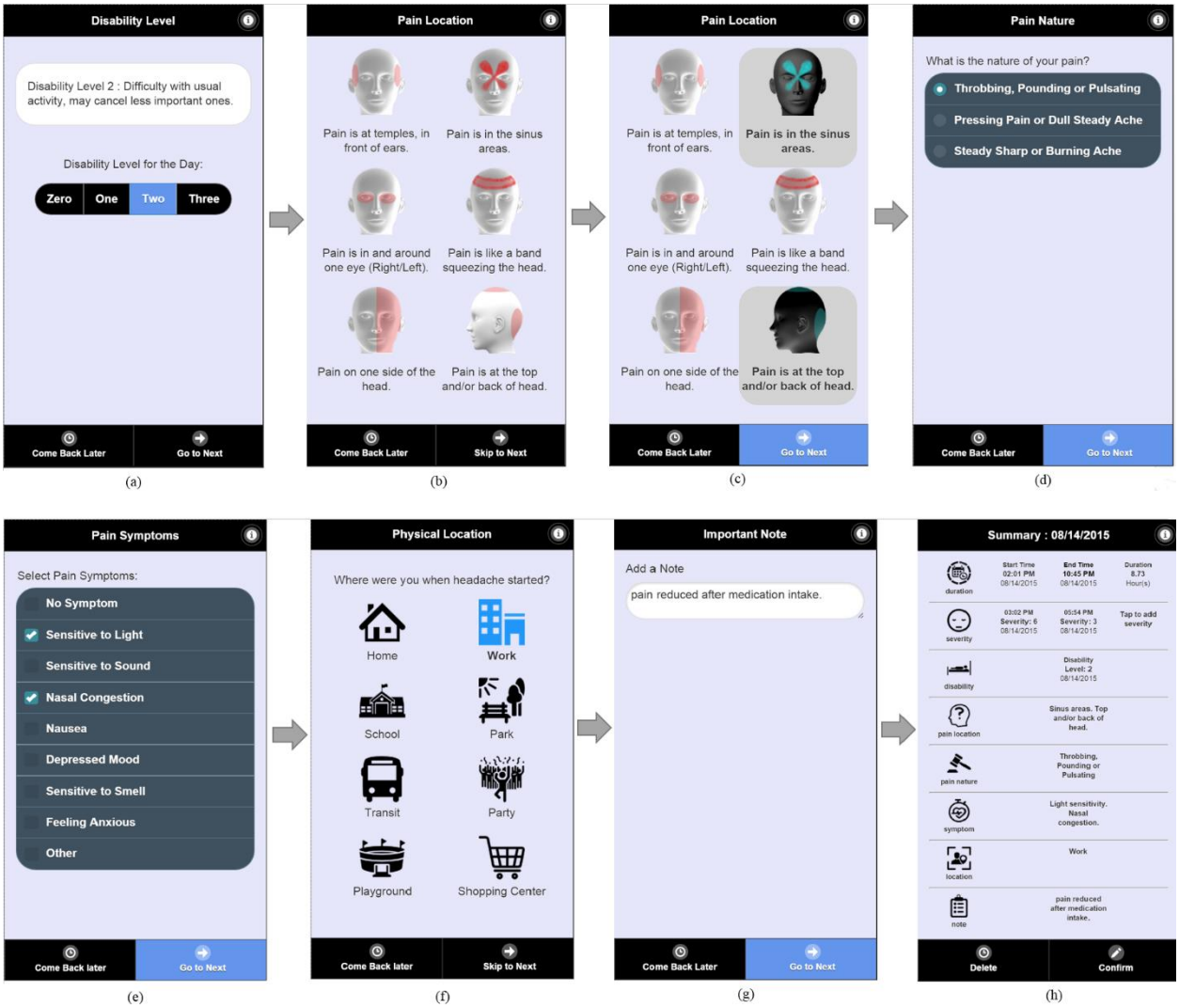


Figure 4.15 (a) Disability level, (b) Pain locations, (c) Selected pain locations, (d) Pain nature, (e) Pain symptoms, (f) User location, (g) Note and (h) Summary

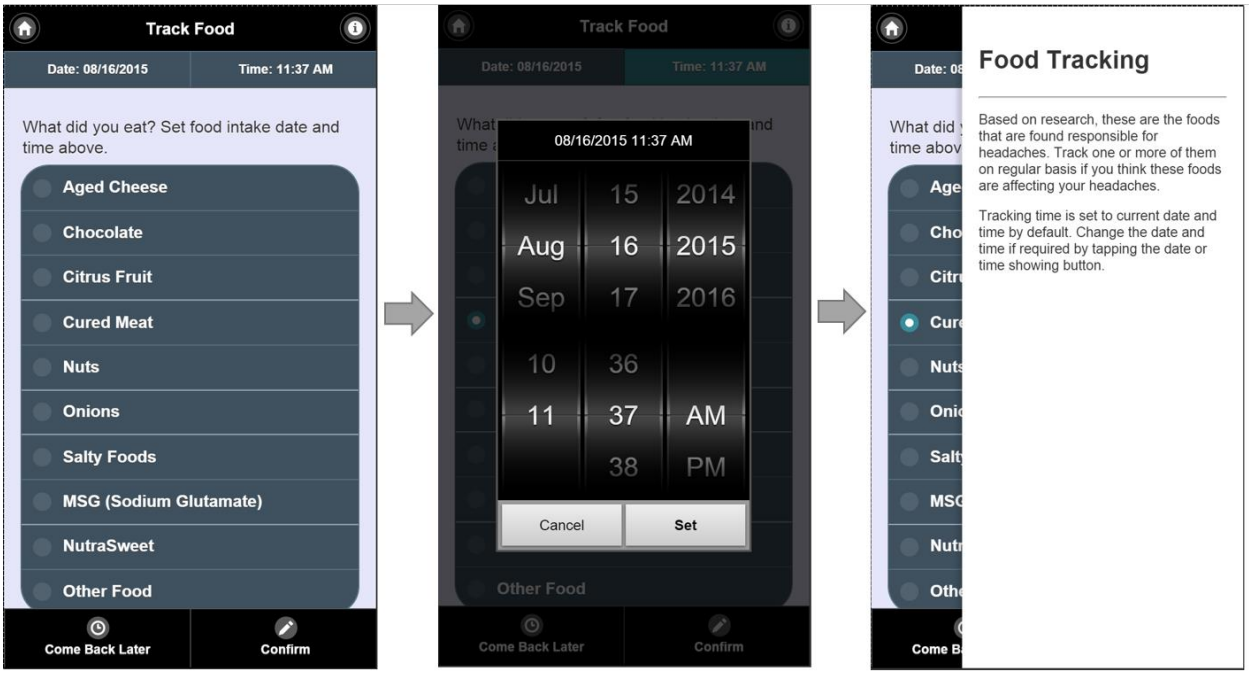
At the end the user can enter free-form text to record any useful information (Figure 4.15 (g)) which was one of the user requirements. A summary of all the parameters entered so far for a headache entry are shown to the user before confirmation (Figure 4.15 (h)). The user can tap on any data parameter to go back to the specific page to update the parameter. The user also has options to either delete the entry or confirm the entry.

4.4.1.2 Activity Logging

Users can track or record different activities or events based on their needs. The "Activities" button directs the user to the activity logging screen. Figure 4.16 shows snapshots of the activity logging main screen.

Figure 4.16 (a) Activity Tracking Main Screen, (b) Activity Tracking Info Panel

Based on the user requirements, activity logging includes options for food, drink, exercise, sleep, stress and menstruation. Also the information panel (Figure 4.16 (b)) shows useful information for the users. Figure 4.17(a) shows different foods that are available to track along with option for tracking other foods which are not available in the list. Users can track the food intake both in-situ and retrospectively by adjusting the date and time as shown in Figure 4.17(b). The info panel shows useful information and instructions for the users (Figure 4.17(c)). Figure 4.18 shows other activity logging interfaces for drink, exercise, sleep, stress and menstruation.



(a) (b) (c)

Figure 4.17 (a) Food Tracking Main Screen, (b) Adjusting Date and Time for Food Tracking and (c) Food Tracking Info Panel

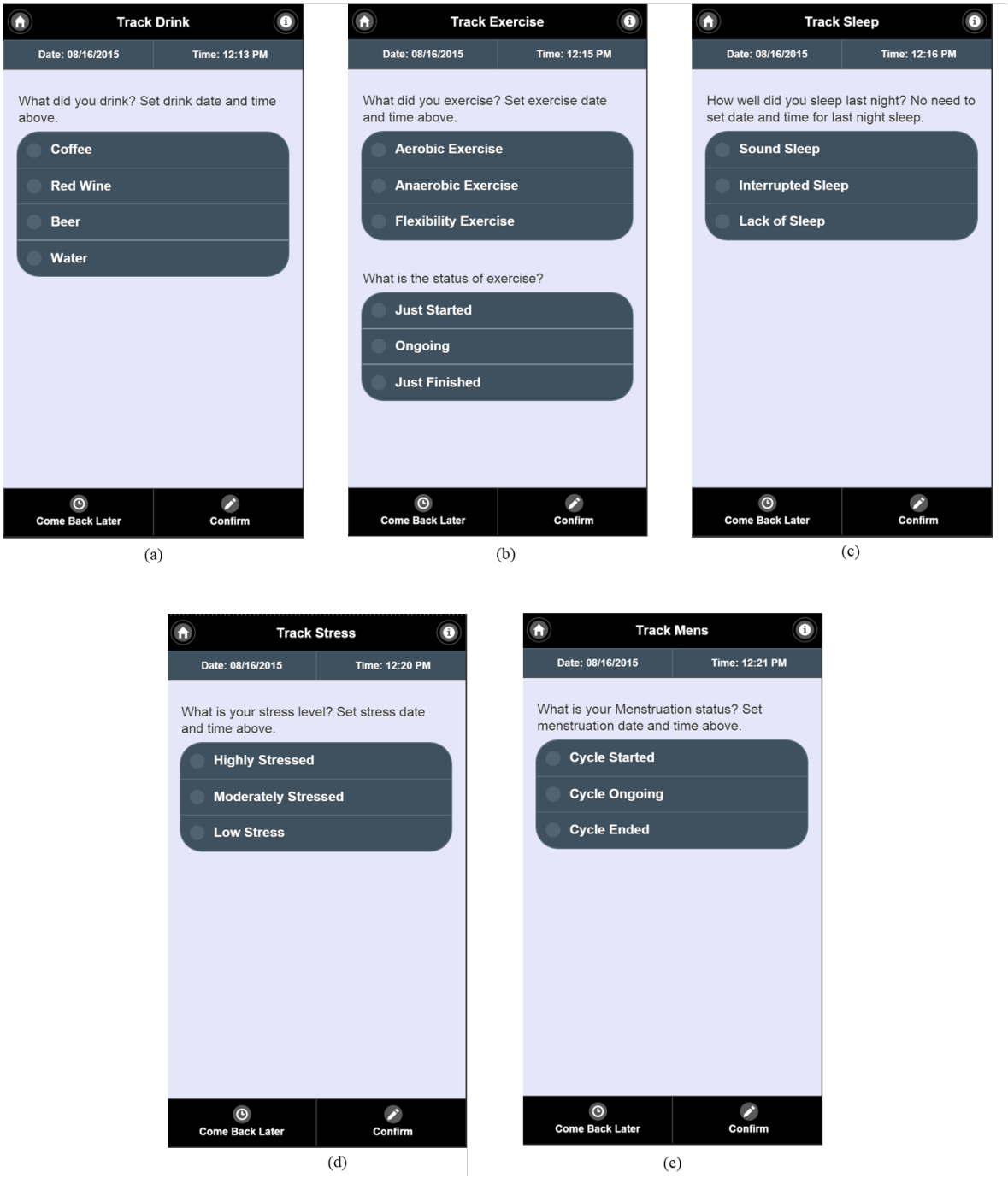


Figure 4.18 (a) Tracking Drink, (b) Tracking Exercise, (c) Tracking Sleep, (d) Tracking Stress and (e) Tracking Menstruation

Since the target users of HeadacheTracker are new to data collection, they are more interested in identifying their own headache triggers rather than experimenting with different headache triggers. This is why the activity logging interfaces are designed to track activities at a high level. For example, for tracking drinks the required parameters are the name of the drink and drinking time but not the measurement of drinks (i.e. 3 cups of coffee). This information is sufficient to perform a temporal analysis to find out how the drinking is affecting headaches.

Users also wanted to track weather data to analyze its impact on headache frequency. The HeadacheTracker application tracks weather data automatically, without any user input, once in every hour and uses the data in visualization of headache day recorded events. Users do not need to configure anything or track weather data manually.

4.4.1.3 Medication Tracking

There are two types of medications headache patients take: symptomatic medication and preventive medication. Headache patients take symptomatic medication to get relieved from an ongoing headache. Preventive medication is taken regularly to prevent headache attacks. The "Medications" button takes the user to the medication tracking screen. Figure 4.19 shows different screens for medication tracking. Medication intake date and time, medication name and quantity are required parameters to track based on user requirement.

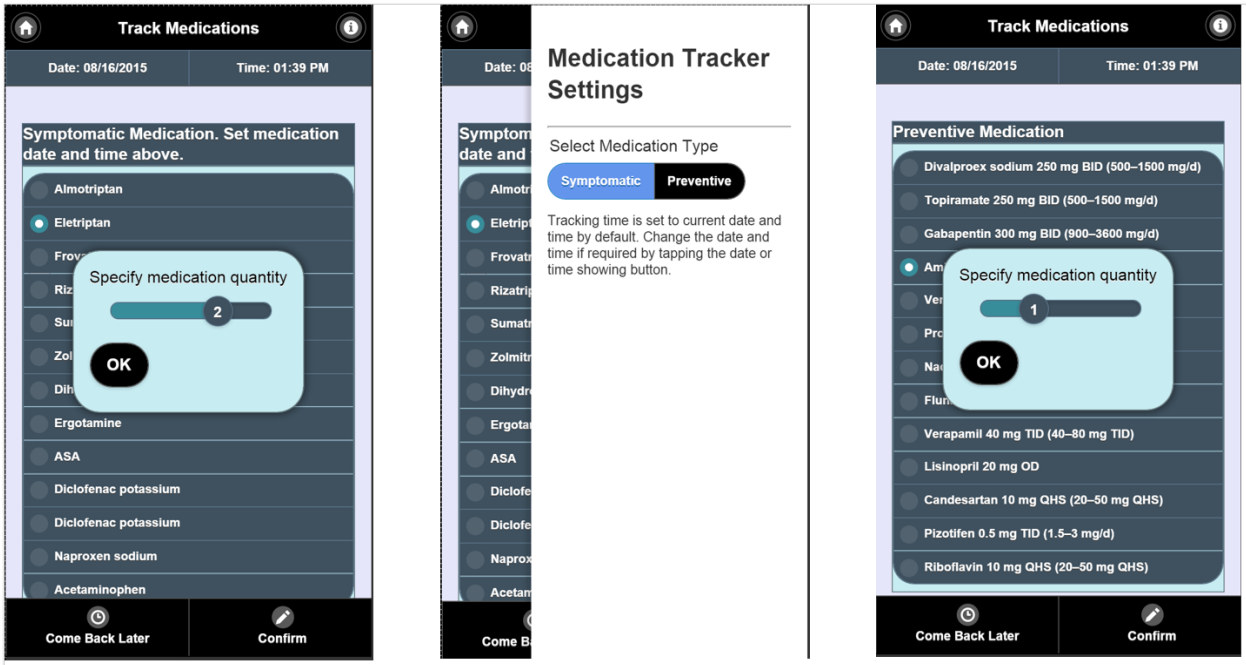


Figure 4.19 (a) Symptomatic Medication Tracking, (b) Medication Tracker Setting, and (c) Preventive Medication Tracking

4.4.2 Data Analysis Interfaces

4.4.2.1 Review of Headache Trends

Often headache patients visit their clinician to discuss their conditions. They find it challenging to express their conditions due to lack of aggregated knowledge about own condition. Patients want to understand trends or patterns of their headaches. Based on the collected headache parameters, different aggregated visualizations are generated by the HeadacheTracker application. Headache patients can find these under the "Review" button of the "Analyze" section. Figure 4.20 shows different trends of patient headaches based on collected data. Headache patients can scroll down the page to review different trends of headaches.

Figure 4.20 (a) Headache Start Time Distribution, (b) Headache Duration Trend, (c) Headache Severity Trend, (d) Headache Disability Trend, (e) Headache Pain Location Distribution, (f) Headache Pain Nature Distribution, (g) Headache Symptoms Distribution, and (h) Physical Location Distribution during Headaches

4.4.2.2 Exploring Particular Headache Day

Very often when a headache patient experience a headache, he/she wants to know what went wrong that he/she is having a headache. So, the patient wants to review the past events and activities to figure out probable headache trigger or triggers. The “Explore” link under “Analyze”

supports this requirement by allowing a patient to review all the headache days in a calendar view and letting him/her explore events on a particular headache day. The representation of the events are separated by different segments of the day (e.g. morning, afternoon) to make it more readable for the users. A few participants in the requirements elicitation study said that weather (e.g. chinook wind) is a potential trigger for them. In the headache day exploration view, weather data is shown for each segment of the day. By exploring the collected data in this manner, a user can review all the things or events he/she went through before having a headache and may notice changes in weather, stress level or other recorded events from one segment to another segment of the day. Based on this the user may generate data-driven conjectures about the potential headache trigger or triggers for the particular headache day. Figure 4.21 shows the visualizations under "explore" link.

Figure 4.21 (a) Calendar View, (b) Recorded Events (Top), (c) Recorded Events (Bottom)

4.4.2.3 Comparing Impact of Headache Triggers

Headache patients always try to identify what factors are responsible for their headaches. Using the HeadacheTracker, they can track multiple activities and events to understand if those factors are influencing the onset of their headaches and to what extent. This task requires temporal analysis of collected data along with probabilistic calculation. As headache patients may not be trained in temporal data analysis or probabilistic calculation, an interactive visual analytic interface can help them to achieve their goal. At the minimum, headache patients want to see to what extent a trigger factor (tracked activity or event) is correlated or not correlated with his/her frequency of headaches. So, the visual analytic interface should allow a headache patient to see how a single factor is potentially correlated or uncorrelated with his/her headaches. The interface should also show a comparison of different tracked activities or events with respect to their level of potential correlation with headaches so that the patients have an idea of the factors that are more potentially correlated with their headaches. As described in Section 2.4, it usually takes more than one factor to trigger a headache. So, the visual analytic interface should allow the patients to interact with potentially correlated trigger factors to see how a combination of two potential trigger factors may increase the likeliness of having headaches when both of the factors are present within same day. Figure 4.22 shows the interactive visual analytics interface that shows all this information to a headache patient. In Figure 4.22(a) headache patients get the following information:

- All the self-tracked factors that are potentially correlated with a patient's headaches sorted in descending order. For example, in Figure 4.22(a), factors responsible for headaches are high stress, lack of sleep, moderate stress, interrupted sleep and coffee where high stress is relatively more correlated with the frequency of headaches than other trigger factors.

- For each headache trigger factor a bar represents percentage that the factor was present before headache (in blue) against the percentage the factor was present but no headache occurred (in orange).
- Right side information panel (Figure 4.22(b)) emphasizes the fact that the level of correlation of a trigger factor with headaches can be more realistically estimated if several months of data (higher number of occurrences of headaches and triggers events) is collected by the user.

Figure 4.22 (a) Chart showing impact of Headache Triggers and (b) Information Panel

Users can interact with the chart in different ways. For example, a user can tap a trigger bar to view details about the trigger factor. The message box at the bottom of the chart provides

an explanation about the trigger factor. There is also instruction on how to see combined effect of two trigger factors on headaches. Figure 4.23(a) shows the message box with trigger factor details and instruction to view the combined effect of trigger factors. Figure 4.23(b) message box provides information on currently selected trigger factor along with combined effect of current and previously selected trigger factors. The objective is to provide a better idea about how a combination of two trigger factors may increase the likeliness of the patient's headache frequency.

Figure 4.23 (a) Message showing Single Trigger Impact and (b) Message showing Combined Impact of Two Triggers

Users can also change the duration for which the chart shows the level of correlation or no correlation of potential trigger factors with the frequency of headaches. For example, a user can compare impact of headache triggers for last 1 month as shown in Figure 4.24(a) and review the same for last 1 week as in Figure 4.24(b). The difference between the two charts suggests that the

estimate of the level of correlation between the potential trigger factors and headaches depend on the number of times a patient tracks the potential triggers and also the number of times a patient experiences headaches afterwards. This resembles the relative frequency notion of the probability. For example, the higher the number of times a coin is tossed, the closer its relative frequency gets to its actual probability of having a head or tail.

Figure 4.24 (a) Impact of Triggers (Last 1 Month) (b) Impact of Triggers (Last 1 Week)

4.4.3 Comparing the HeadacheTracker with existing applications

In Section 2.6, an overview of the issues with the existing applications were presented. Below, Table 4.1 presents how the HeadacheTracker requirements address the issues found in the literature study of the existing applications for chronic headaches.

Table 4.1 Comparison of the HeadacheTracker with existing applications

Name	Number of App criteria met (described in Section 2.6)	In-situ collection of putative headache triggers	Visualization showing headache trends	Visualization showing recorded events on a particular headache day	Visualization showing correlation between putative headache triggers and headache attacks
iHeadache	5	No	No	No	No
ecoHeadache	5	No	Yes	No	No
Headache Diary Pro	5	No	Yes	No	No
Migraine Diary	4	No	Yes	No	No
PainCal	4	No	Yes	No	No
A Migraine Diary for You	4	No	Yes	No	No
Curelator Headache	Not evaluated yet using the criteria	Yes	Yes	No	Yes (not interactive, need to wait 45-90 days to review report, combined effect not shown, need to comprehend p-value statistic to understand correlation)
HeadacheTracker	6 (criteria 7 was out of scope)	Yes	Yes (shows more trends than other apps)	Yes	Yes (interactive, allows to explore multiple time windows, no need to wait for long time, shows percentage of potential

					correlation between headaches and triggers, combined effect of two putative triggers is shown)

4.5 Chapter Summary

In this Chapter, the design and development of HeadacheTracker is discussed. I elaborate the methods, tools and techniques that I have used in the design and development process. I also give rationales for using specific methods and platforms. Finally, I describe the user interfaces of the HeadacheTracker application to demonstrate how the user requirements are addressed in the design of tracking and visualization interfaces to help headache patients.

Chapter Five: **Evaluation Study of the HeadacheTracker**

The goal of my research is to help headache patients understand their headache triggers and headache trends by allowing them to interactively track, analyze and explore self-tracked headache data. To achieve the goal, in the first step, I have conducted the user research to understand their requirements for headache data tracking and analysis. In the second step, I have developed a smartphone-based application (functional prototype) addressing the elicited requirements. In Chapter 4, I have described and discussed how I have addressed the requirements in the design and development of the HeadacheTracker application. To validate the fact that the developed application can actually help headache patients by fulfilling their needs (discussed in Section 3.2), I have conducted an evaluation study of the HeadacheTracker application. The primary goal of the evaluation study was to test the usability (fit for purpose) of the HeadacheTracker application. Overall, the study results show that the users perceived the HeadacheTracker application useful in tracking headache data according to their need. The users also expressed that the interactive visualizations of the HeadacheTracker would be helpful in identifying potential headache triggers. In this chapter, I discuss the overall evaluation study of the HeadacheTracker application and provide the details of the study results.

5.1 Evaluation Study Design and Rationale

The objective of the HeadacheTracker evaluation study was to understand the users' perspectives on how and to what extent the application may help them to increase their knowledge about their own headache trends and triggers. To achieve the objective, I chose observational techniques [11] to gather information about the actual use of the application by the users (CHAMP headache patients). I conducted the evaluation study in a laboratory environment in which I held one-on-one evaluations (30-45 minutes) of the HeadacheTracker application. This was done due

to the advantage of laboratory-based study where I could conduct the usability study by observing user tasks and afterwards reflecting on the tasks in a post-task walkthrough study [11].

In the study, the users were given tasks to interact with the data collection and data visualization interfaces and then they were asked open-ended interview questions to reflect on their experiences about the utility of the application. In addition, to determine the ease of use of the data collection interfaces, I asked identical questions using likert scale to all participants for each data collection task using the HeadacheTracker. To be able to evaluate the data visualization interfaces, I generated imaginary headache patient data for one month to populate the HeadacheTracker application. The visualizations were based on the populated data. For both the data collection and data visualization interfaces, the post-task open-ended interview questions allowed me to capture how headache patients perceived the usefulness of the application. The interview questions were worded so that the responses are open-ended from the participants. The objective was to allow participants to contribute as much detailed information as they desire. As I received subjective feedback from the participants for the interview questions, I decided to qualitatively analyze all user responses to evaluate the HeadacheTracker application.

Instead of laboratory-based study, I could conduct a field study but I did not do that for several reasons. Field studies allow users to perform tasks in their natural environment but provide less control over user activities and interpretation of the activities. Another reason not to do a field study, in the context of my thesis, is that the field study would involve significant process change at CHAMP clinic (i.e. allowing patients to use the HeadacheTracker for few months over paper-based diary). This would require the HeadacheTracker application to have stringent security for protecting user's health data and additional functionalities to support downloading and sharing of

health data with a CHAMP doctor during the follow-up visit. These would require significant time and effort to implement and was not within the scope of my research project.

5.2 Evaluation Study Description

In this section, I describe how I conducted the actual laboratory-based evaluation study of HeadacheTracker. I also discuss how the participants were recruited and what methods and tools were used in the study to evaluate HeadacheTracker.

5.2.1 Participant Recruitment

My original intention was to go with the same participants who attended the requirements elicitation study. All of them signed the consent forms expressing their interests to participate in the evaluation study during the requirements elicitation study. When the HeadacheTracker development was finished, I reached out to all participants but only 3 of them responded positively. The other participants were either moved to other locations permanently or found other programs to manage their headaches. I attended 2 headache education sessions and recruited 4 new participants for the evaluation study. That means, there were total 7 participants (3 old and 4 new) for the evaluation of HeadacheTracker application. Research indicates that user interface testing with 5 users can identify most of the usability problems [32, 33]. I recruited more than 5 users just to make sure that I am receiving enough feedback for analysis.

Table 5.1 Participant Information for HeadacheTracker Evaluation Study

Participant	Age	Sex	CHAMP Diary Experience	Status
P1	48	Male	3 months	Old Participant
P2	33	Female	1 month	New Participant
P3	20	Female	More than 1 year	Old Participant
P4	34	Female	3 months	New Participant
P5	50	Female	No experience	New Participant
P6	35	Female	2 months	New Participant
P7	35	Female	6 months	Old Participant

5.2.2 Apparatus

I conducted the evaluation study by asking interview questions, providing task scenarios to the participants and reflecting on their experience after the completion of given tasks. I used the following apparatus during the evaluation study:

- HeadacheTracker: A mobile web application for tracking and analyzing headache data using visual analytic interfaces.
- Audio recorder: The recorder was used to record the whole interview session for further analysis of interview data.
- Pen and paper: I wrote down my observations and notes while the participants were executing the tasks using HeadacheTracker.

5.2.3 Evaluation Study Procedure

The whole evaluation study can be divided into 3 distinct parts:

1. A pre-task interview to learn about current status of each participant with respect to data collection practices and knowledge of own headache triggers.
2. An evaluation of the data collection interfaces based on tasks and a post-task interview.
3. An evaluation of the data visualization interfaces based on tasks and a post-task interview.

5.2.3.1 Pre-task Interview Questions

I asked the pre-task interview questions with a view to understand the current status and habits of the participants with respect to their headache data tracking and analysis of collected data. The objective was to use the current status as a baseline so that after the evaluation study I can compare the baseline with the results of the evaluation study to understand how they can use

the HeadacheTracker application to overcome the issues they currently encounter. I asked the following questions shown in Table 5.1 before conducting the main evaluation study.

Table 5.1 Pre-task Interview Questions

Serial	Interview Question	Objective
Q1	In what frequency do you collect headache data? Once a day or multiple times a day?	To know about participant's current data collection habit.
Q2	How did the data collection help you so far? What kind of insight did you get from collected data?	To learn about participant's overall understanding about their headache condition based on his/her headache data collection practice.
Q3	How well do you know your headache triggers now since the last time we met? (applicable for the old participants only)	To learn specifically if the participant's current data collection practice helped him/her to identify his/her headache trigger.

After asking the pre-task questions, I introduced the HeadacheTracker application to the participants by providing a brief overview of the home page and by discussing functionalities of different buttons on the home page on a high level.

5.2.3.2 Evaluation of Data Collection Interfaces

To evaluate the data collection interfaces, I created several data entry tasks for the participants and asked them to perform the tasks one by one. The tasks for data collection interfaces are described in Table 5.2.

Table 5.2 Tasks for Data Collection Interfaces

Serial	Task	Objective
T1	Suppose you had a headache today from 10am to 2pm and usually you collect data every day once at night. Create a new headache entry for the headache using HeadacheTracker.	To observe how the users perform retrospective headache entry.

T2	Suppose your headache started about 30 minutes ago and it is currently ongoing. Create a headache entry for your ongoing headache and exit the application to come back later.	To observe how the users perform in-situ headache entry without finishing the entry.
T3	Suppose your ongoing headache ended about 15 minutes ago. Update and finish the ongoing headache entry that you created earlier.	To observe how the users update a headache entry when the headache ended.
T4	Suppose you have a feeling that "Aged Cheese" and "Coffee" intake trigger your headaches and you track them as you take them throughout the day. Make an entry for "Aged Cheese" which you took at 8am and then another entry for "Coffee" which you took just a while ago.	To observe how the users perform tracking of daily activities and events and what problems they face during the tracking.
T5	Suppose, you took medication after your headache started. Create an entry for the medication intake.	To observe how the users track medication and what problems they face during the tracking.

For each task mentioned in Table 5.2, I asked the following questions (Table 5.3) after the corresponding task to capture how easily the users performed each task.

Table 5.3 Post-task Likert Scale Question for Data Collection Interfaces

Serial	Interview Question
Q4	In your opinion, how easy is it to create a new headache entry retrospectively using the app? a) Not easy b) Easy c) Very easy
Q5	In your opinion, how easy is it to create a new headache entry instantly for an ongoing headache using the app? a) Not easy b) Easy c) Very easy
Q6	In your opinion, how easy is it to update and finish a headache entry using the app?

	a) Not easy b) Easy c) Very easy
Q7	In your opinion, how easy is it to track headache triggers or daily activities using the app? a) Not easy b) Easy c) Very easy
Q8	In your opinion, how easy is it to track medication using the app? a) Not easy b) Easy c) Very easy

After completion of all the tasks, I asked few open-ended interview questions to each participant. Table 5.4 shows the post-task interview questions and their objectives for data collection interfaces. The overall objective of these open-ended questions was to understand how participants envision the utility of HeadacheTracker for headache data collection.

Table 5.4 Post-task Interview Questions for Data Collection Interfaces

Serial	Interview Question	Objective
Q9	Based on your overall experience of data collection using HeadacheTracker, can you share how this tool would fit into your daily life with respect to headache data collection?	To allow the users to express their feelings and thoughts regarding data collection using HeadacheTracker. The objective is to learn both positive and negative sides of data collection interfaces of HeadacheTracker.
Q10	As the HeadacheTracker application allows you to track data instantaneously, would you track data once in a day or track as it happens? Why?	To learn about a user's future data collection intent given that HeadacheTracker allows in-situ and temporal data collection.
Q11	Is the HeadacheTracker easy to use and easy to navigate through pages with respect to data collection? What improvements do you see?	To learn specifically if the users are comfortable interacting with the data

		collection interfaces of HeadacheTracker.

5.2.3.3 Evaluation of Data Visualization Interfaces

There are 3 kinds of data visualization interfaces in HeadacheTracker as described in Section 4.4.2. To evaluate each of these interfaces, I asked the users to perform multiple tasks for each data visualization interface. I populated the HeadacheTracker application with imaginary headache patient data to generate visualizations. Although, the data was not entered by the participant themselves, at this stage, they already got familiarized with all the data collection interfaces while performing the data entry tasks mentioned in Section 5.2.3.2.

Table 5.5 shows the tasks that were given to the users to find insights about headache trend from the "Review" page (described in Section 4.4.2.1).

Table 5.5 Tasks for Data Visualization Interfaces (Headache Trend Review)

Serial	Task	Objective
T6	Suppose, one of your friends has collected headache data using HeadacheTracker for the month of April 2015. Now he wants to get some insights from the collected data and needs your help. Find the segment of the day your friend experienced most of his headaches.	To observe if the users can find the required insight (headache trend parameter) correctly by navigating through the "Review" page and to allow the users to reflect on their experiences in the post-task interview.
T7	Find the average duration of your friend's headaches.	
T8	Find the location of your friend's head where he experienced the pain most of the times during his headaches.	

After completion of the tasks mentioned in Table 5.5, I asked the following question (Table 5.6) to the users to get their feedback. The objective was to understand how the users can be benefited from the aggregated insights.

Table 5.6 Post-task Interview Questions for Data Visualization Interfaces (Headache Trend Review)

Serial	Interview Question	Objective
Q12	How do you think these insights can be useful to your friend? Do you have similar kinds of questions in your mind? What would you do if you know the answers to these kinds of questions?	To allow the users to express their feelings and thoughts regarding insights on Headache trend. The objective is to learn whether these insights can help the users or not.

Table 5.7 shows the tasks that were given to the users to find insights from the "Compare" page (described in Section 4.4.2.3).

Table 5.7 Tasks for Data Visualization Interfaces (Compare Triggers)

Serial	Task	Objective
T9	Find the biggest trigger of your friend's headaches based on 1 month of his collected data.	To observe how the users search and find the required headache trigger information by navigating through the "Compare" page and to allow the users to reflect on their experiences in the post-task interview.
T10	Find the least impactful trigger of your friend's headaches based on 1 month of his collected data.	
T11	Find how lack of sleep impacted your friend's headache condition.	
T12	Find the combined effect of "high stress" and "coffee" on your friend's headaches.	
T13	Find how the impact of the triggers have changed over time - last week vs last two weeks vs last month.	

After completion of the tasks mentioned in Table 5.7, I asked the following questions (Table 5.8) to the users to get their feedback on the interface under study.

Table 5.8 Post-task Interview Questions for Data Visualization Interfaces (Compare Triggers)

Serial	Questions	Objective
Q13	How well do you understand the graph to perform the given tasks? What are the limitations of the graph?	To allow the users to express their feelings and thoughts regarding understanding the graphs showing headache trigger information.
Q14	Do you have these kinds of questions in your daily life as you experience headaches?	To learn whether and how these insights can be useful in a headache patient's context.
Q15	What would you do after knowing the insights about your headache triggers? How will the insights help you to manage your headaches?	To learn if the insights are actionable with respect to participant's own headache condition.
Q16	What more would you like to know about your triggers?	To learn about any improvement on the graphs showing trigger information.

Table 5.9 shows the tasks that were given to the users to get insights from the "Explore" page (described in Section 4.4.2.2).

Table 5.9 Tasks for Data Visualization Interfaces (Explore Headache)

Serial	Task	Objective
T14	Find how many headaches your friend had in the month of April.	To observe how the users find the required information using the calendar view of headaches.
T15	Suppose your friend wants to find why he had headache on 8th April. Go to details of 8th April headache and try to find what factors might have caused the headache for him.	To observe how the participants review the sequence of events to generate any conjecture about headache triggers based on the information.

After completion of the tasks listed in Table 5.9, I asked the following questions (Table 5.10) to evaluate the interface under study based on the users' feedback.

Table 5.10 Post-task Interview Questions for Data Visualization Interfaces (Explore Headache)

Serial	Questions	Objective
Q17	How is the sequential view of events or activities separated by segment of the day useful to find out the headache trigger for the particular day? If not useful then why not? How can this be improved?	To allow the users to express their feelings and thoughts regarding exploring a particular headache to identify headache triggers for that headache. The objective is to learn how these insights can help the users.
Q18	Out of all data visualization interfaces which one do you prefer and why?	To allow the users to reflect on the comparative utility of the data visualization interfaces.
Q19	How do you envision using these kinds of graphs in your daily life to analyze and understand your headache triggers? To what extent will it be useful to you?	To allow the users to reflect on the overall utility of the data analysis and visualization interfaces in their daily life.

5.3 Evaluation Results and Discussion

In the evaluation of HeadacheTracker, I asked open-ended interview questions to understand how the headache patients perceived the benefits of using HeadacheTracker in fulfilling their needs. To make the difference evident, I captured the feedback of headache patients before and after using the HeadacheTracker application. I provide the results of evaluation below under several high level themes followed by brief discussions on the results.

5.3.1 Effective Data Collection

After each data collection tasks (T1 to T5), I captured user feedback on the easiness of data collection task using the HeadacheTracker data collection interfaces. Table 5.11 shows the frequency of user feedback (easy, not easy and very easy) for each data collection task based on the questions in Table 5.3.

Table 5.11 Frequency of Easiness Rating for Data Collection Tasks

Serial	Very Easy	Easy	Not Easy
T1	4	3	0
T2	3	4	0
T3	3	4	0
T4	3	4	0
T5	2	5	0

The user responses shown in Table 5.11 confirm that the data collection tasks were easy to perform using the data collection interfaces. Nevertheless, users also identified a few improvement areas for the data collection interfaces. For example, participant P2 pointed out that there should be an "other" option in addition to the options already provided for physical location of the user (Figure 4.14 (f)). Participant P2 expressed her interest for tracking start and end time for sleeping in addition to sleep quality (Figure 4.17 (c)). Participant P4 discussed the need for an option to record any other medication which is not available in the medication list.

In response to the interview question Q9 (Based on your overall experience of data collection using HeadacheTracker, can you share how this tool would fit into your daily life with respect to headache data collection?), all of the participants expressed that HeadacheTracker would definitely fit into their daily life with respect to headache data collection. I found that all the participants considered the application very much suitable for in-situ and retrospective data collection. For example, in response to Q9, P1 said, "*…to be perfectly honest with you in my collection of data, I'm not just a write things down type of person, I prefer a quick simple interaction with something and then move on, right or wrong, but that's me, so I'm more likely to do something where I can do a quick little couple of things and then move on and so having it as an app makes sense…*". In response to the same question, P2 said, "*I think that everything is really easy to use, um, I think that, yeah, the main thing for me is the customization, um, and it would be*

useful to be able to track everything in one app…". This means tracking all of the temporal events or activities using a single app provides convenience for the users in their everyday data collection. Participant P4 said that using HeadacheTracker would be much more convenient for her as she would like to collect data on the go and this way she could maintain the data accuracy without trying to remember or recall everything at day end. Participant P3 said, "*…I think it will be very helpful for me to track everything and it's going to be really easy as I'll have it on my phone so that I can just do it quickly because generally I always have my phone with me…*". P6 said, "*...I definitely think it would fit much better than the paper diary for sure, it kind of reminds me of my running app or my exercise app, I can't say for sure but it would probably be similar to that, I use it for tracking everything intelligently and multiple times a day. So yeah, I think it will be way more useful than a paper diary…* ". Participant P7 said that as it is quick and easy, it would fit nicely into her daily life but with one exception because she does not take her phone to bed so it might not be possible to collect headache data at that moment.

In response to the interview questions Q10 (As the HeadacheTracker application allows you to track data instantaneously, would you track data once in a day or track as it happens? Why?), all of the participants emphasized on the benefits of combining in-situ and multiple time data entries. For example, P1 said, "*…I think this would depend on the day, when the day permits, I would be tracking on the go, because it would be best for me… and I think outside, you know, being in a place where you can't really pull up your phone angd start entering the data then I would go to the end of the day type thing but our days are busy so it's kind of hard to remember exactly what happened and the measure of the data, the quicker you get it in there the more accurate it is, the more you will be able to figure out what the heck is going on…*". Participant P7 said, "*I think I am more likely to track as it happens, because I always have my phone with me*

during the day…". Similarly, most of the participants expressed the usefulness and necessity of frequent in-situ data collection since HeadacheTracker application supports it very well.

In response to interview question Q11 (Is the HeadacheTracker easy to use and easy to navigate through pages with respect to data collection? What improvements do you see?), most of the participants said that the application is easy to use and easy to navigate based on their interaction with the application. Participant P4 pointed out that after logging any activity the page does not show any confirmation or instruction about the next step which confused her for a moment about what to do next.

5.3.2 Understanding of the Headache Trends

The graphs under the "Review" (Figure 4.19) button in HeadacheTracker show headache trends of a headache patient. Based on my observations, all of the participants found the headache trend parameter correctly when they were asked to perform tasks T6, T7 and T8. While performing the task T8, participants P2, P4 and P6 had difficultly to separate different colors in the pie chart and suggested using more contrasting colors.

In response to interview question Q12 (How do you think these insights can be useful to your friend? Do you have similar kinds of questions in your mind? What would you do if you know the answers to these kinds of questions?), P1 said, "*…well, if it was for me, I would just have better idea of what I am likely to, which will actually help me in identifying them…*". Participant P3 expressed the same more clearly, "*…he can look back and see the amount of time or the percentage of time that all of these occur to kind of see there is one, like major aspect to his headaches that may be he needs to focus on or like, pain location, its quiet broken down, so that's, you know, he has quite a few different areas in that sense but like location – during headaches, you know, he has 50% of the time they have started at home, so maybe he needs to do something*

about his home environment… ". She also mentioned that understanding these trends would help her to communicate her condition with the doctor. In her own words she said, "*…and also of course have that information with me when I do see my doctor and talk to them about that – this is something that I have noticed to see if they have any suggestions for me…*". Participant P7 also said about utilizing the headache trends when she would visit the doctor, "*…I keep notes on my phone but sometimes it gets too much that my doctor doesn't want to look at it because there is too much information, this is easy just to like bring up, you know, one screen instead of my pages and notes…* ".

5.3.3 Understanding of the Headache Triggers

The visualization under the "Compare" (Figure 4.21) button in the HeadacheTracker application shows the extent a trigger factor (represented by each bar) is correlated or uncorrelated with the frequency of headaches. The bars (tracked factors) are sorted in a descending manner to indicate high to low correlation of trigger factors with headaches. Based on my observations, most of the participants found the correct answers for the tasks from T9 to T13. Participant P6 could not interpret the significance of the horizontal bar at first sight and asked for clarification. While trying to find the biggest trigger (T9), participant P6 could not realize the difference in the bars (Figure 4.21) at first sight as all of them are of same height. After taking a closer look she realized that each bar is divided into two parts (headache and no headache) separated by colors (blue and orange). Participant P2 and P6 had a little difficulty in finding combined effect of two triggers (T12) as they overlooked the text message under the visualization which has instruction on how to find the combined effect.

While reflecting on the tasks and answering Q13 (How well do you understand the graph to perform the given tasks? What are the limitations of the graph?) and Q14 (Do you have these

kinds of questions in your daily life as you experience headaches?), most of the participants stated that they understood the graph without difficulties and always wanted to know these kinds of insights about their own headache triggers. As Participant P6 experienced difficulty to understand the visualization, she suggested a different approach using Venn diagrams to show similar insights. She said, "*...may be more like, uh, a Venn diagram with different sizes, this is like high stress and it was only on 4 days and then this is not sleeping and drinking coffee, like different sizes represent how many days a month and then may be like percentages in each thing so that you can really easily see the impact of different things together...*". This implies that the temporal analysis to show potential correlation of each factor with headaches should be represented in different manners so that users can switch between multiple representations to understand the potential headache triggers.

In response to interview question Q15 (What would you do after knowing the insights about your headache triggers? How will the insights help you to manage your headaches?), participant P1 said, "*...I will look at the top, top 3, just because they will have such a large impact on the overall number, so, I will be looking at those as my starting points. I would be interested in going back in the data just to see and switch over the combinations, but yeah that's the way of just figuring out for yourself clicking back and forth… when I am having high stress, I probably shouldn't have a coffee…* ". This response implies that the participant P1 became able to interact with the visual analytic interface (Figure 4.21) to explore potential headache triggers based on analytics and became curious to explore impact of combined factors to make informed decisions to avoid potential headache triggers in future. Participant P3 said, "*...I would probably try and find trigger combos, to see if there was, um, if there were two things that were happening together that like had high increase in headaches for me and again, yeah, taking that information to my doctor,*

kind of like letting them know what kind of trend I am tracking…". Similarly, other participants also expressed their interest to find potential headache triggers based on the visualization.

5.3.4 Data Driven Conjectures about Headache Triggers

Based on my observation, all of the users could correctly count the number of headaches from the calendar view (T14). While performing T15, all of the users carefully observed the sequence of events and came up with similar conjectures about potential headache triggers for the particular headache. This confirms that the interface supports data-driven conjecture generation about headache triggers.

In response to interview question Q17 (How is the sequential view of events or activities separated by segment of the day useful to find out the headache trigger for the particular day? If not useful then why not? How can this be improved?), participant P1 said, "*…yeah, the breakout is, it took a few sights just to realize what it is doing but going back to it now, I would know what I was looking for…* ". Participant P2 said, "*...I think that being able to see the temperature, humidity and pressure laid out there is really useful… I like that view, I like that view a lot…*". Similarly, participants P3 P5, P6 and P7 said that the view (Figure 4.20 (b), Figure 4.20 (c)) will help the user to identify what went wrong on a particular headache day based on the data. Participant P4 had difficulty to interpret the view as she had to look back and forth to understand what was going on throughout the headache day. She suggested to use a graphical view (i.e. line graph) to show changes in different parameters.

For interview question Q18 (Out of all data visualization interfaces which one do you prefer and why?), participants stated that all of the visualizations are useful from different perspectives. For example, P3 said, "*...I think, all of them are pretty helpful, but helpful in different ways may be, like this one would be more helpful to kind of see boom boom boom, this is kind of*

timelines of what happened in your day and to see if there is any major thing happened and the other one is more like an overview of headaches, in general, you know, like what seems to be the biggest trigger…". Participants with continuous headaches (P2, P3) liked the headache day view of events (Figure 4.20 (b), Figure 4.20 (c)), because as their severity of pain changes over time in a day, they are able to go back in time to check what events happened earlier to identify a probable headache trigger.

For interview question Q19 (How do you envision using these kinds of graphs in your daily life to analyze and understand your headache triggers? To what extent will it be useful to you?), all participants expressed that the visual interfaces are useful to understand their headache trends and headache triggers which is very critical for self-management of chronic headaches. For example, participant P1 said, "*I would definitely be using this app for a certain period of time… I like the idea of breaking things down just to see the correlations of things…*". Participant P6 said, "*…um, I'm really a visual person so seeing something like seeing all the graphs and then say okay there is a pattern here, there's something I need to change, you know, something to be looked at here…* ".

5.3.5 Comparing Pre-task Interview Responses with Post-task Interview Responses

After the evaluation study, I also compared my findings with the pre-task interview responses. In the pre-task interview, most participants stated that they collect headache data at the end of the day using the CHAMP paper-based diary. All of the participants mentioned that it was hard to track different activities or events on their own and they were unable to find any significant insight related to headache trigger from the collected data. When I asked about how well they knew their own headache triggers, most of the participants said that they have speculations about their headache triggers but do not know for sure if the speculations are correct. After the evaluation

study, based on the responses of the participants I found that HeadacheTracker was perceived as a useful tool for headache data collection. Participants also responded positively about the fact that the application would fit into their daily life for data collection. After executing the tasks for data visualization interfaces, I found that those are also perceived as helpful to the participants as they could envision using them for understanding their headache trends, communicating their trends to clinicians, identifying probable headache triggers based on temporal analysis and inspection of timeline events. The above comparison shows that HeadacheTracker was perceived as a useful and helpful application by headache patients in self-monitoring of chronic headaches.

5.4 Study Limitations

I conducted the study in a lab setting. This means that participant responses were based on their experience and understanding of HeadacheTracker within a short time. In a field study, headache patients could have more time to experience HeadacheTracker to find other issues which they could not figure out within short time in the lab-based study. Each evaluation session lasted about 30-45 minutes including brief introduction of HeadacheTracker, different tasks for users and open-ended interview questions. Longer sessions could lead to more user feedback based on longer period of usage of HeadacheTracker.

Within the study time period, the users were asked to perform a set of predefined tasks only to test the usability of the HeadacheTracker application. If the users were allowed to do all the things they would like to do with the HeadacheTracker, the users could get more involved to explore different features of HeadacheTracker and might come up with more valuable feedback.

The headache data used to generate visualizations was not any patient's actual data. If I could allow participants to track their own data (field study), they could have more perspectives

on how they would like to explore the data to find useful insights. The number of participants could be larger to get more feedback.

5.5 Chapter Summary

The objective of the evaluation study was to find out if and how the HeadacheTracker application can help headache patients analyze and understand their headache triggers by tracking their headaches and headache triggers in a convenient manner. The evaluation results show that the users perceived the HeadacheTracker application useful in tracking and analyzing headache data. The results also suggest that by addressing the user requirements, the HeadacheTracker application can help the headache patients increase their knowledge and understanding of own headache triggers which is critical and important requirement for self-monitoring of chronic headaches. The results and the perceived benefits of using HeadacheTracker are encouraging from a lab-based study and can be utilized to design improved tools for chronic headaches.

Chapter Six: **Conclusion and Future Work**

In this thesis, I presented the HeadacheTracker, a mobile web application to help headache patients by enabling them to track and analyze headache data interactively to review headache trends and identify probable headache triggers. First, the overall motivation behind creating the HeadacheTracker was presented to understand the context in which it would be utilized. Next a discussion on the background and relevant literature was presented. Following this, I described the requirements elicitation study for the HeadacheTracker where I analyzed interview responses of headache patients to understand their needs. My research questions were "*How should we design an application to facilitate headache data collection to address the needs of headache patients??*" and "*How should we design the visual analytic interfaces that facilitate exploratory analysis of potential headache triggers that may cause headaches?*". I explored answers to these questions by converting the headache patients' needs into the HeadacheTracker application requirements. Next, I discussed how the elicited requirements influenced the design and development of the HeadacheTracker. Finally, I provided the results from the evaluation of the HeadacheTracker which confirmed that I met my research goal of helping headache patients by developing the HeadacheTracker based on the elicited requirements.

In this chapter, I summarize the contributions of the thesis and discuss the implications of the evaluation results. This is followed by an overview of possible future work in this area and finally the conclusions of this thesis.

6.1 Research Contributions

The contributions of the thesis are as follows:

1. I have provided an overview of the current research space for designing self-monitoring applications for chronic headache patients and discussed the gaps or improvement areas.
2. I have elicited a set of requirements to design a self-monitoring application for chronic headache data collection and analysis – the requirements are based on a qualitative study of the user (chronic headache patients) needs. The main contribution of the study is separating the needs of different groups (i.e. new to data collection, experienced in data collection) of headache patients and elicit the HeadacheTracker requirements reflecting the needs of the target group of headache patients.
3. I have illustrated how the requirements were addressed in the design and development of the HeadacheTracker by following user-centric approaches to fulfill the needs of the headache patients.
4. I have demonstrated that the HeadacheTracker application can help headache patients track headache data effectively in their daily life to enable them reviewing headache trends and generate data-driven conjectures about potential headache triggers based on insights from interactive visual analytic interfaces. I have effectively used conditional probability and relative frequency to show potential correlation between self-tracked headache triggers and headache attacks based on automated temporal analysis of collected data. The evaluation results of the HeadacheTracker suggest that the application facilitates generating visual analytic

insights for headache patients by allowing interaction with temporal data in an effortless manner. The insights can help headache patients to increase their knowledge about their own headache triggers.

The results of the evaluation study also imply that the overall approach followed in this thesis to design the HeadacheTracker is effective for designing self-monitoring applications. When properly designed, self-monitoring applications can potentially encourage users to actively engage in the management of chronic conditions by enabling them to reflect on the self-tracked data. Combining temporal analysis with statistical computation and generating visual insights based on the underlying computation is highly useful for chronic patients since they can act upon the insights and adjust their lifestyle if required. Interactive visual analytic interfaces may reduce the burden on the chronic patients to spend hours analyzing their own data to figure out what they might do to improve their chronic condition.

6.2 Future Work

In this thesis, I have designed and developed a self-monitoring application for headache patients who are new to headache data collection and also have a headache start time and end time. Combining temporal analysis with conditional probability and relative frequency concepts, I have shown the percentage (and frequency) of possible correlation between potential headache triggers and headache onsets. As headache onset is often triggered by more than one factor, I also have shown combined effects of two potential headache triggers based on a similar temporal analysis. An obvious direction of future work can be improving the HeadacheTracker based on the user feedback from the evaluation study and do a field study for several months to observe the HeadacheTracker usage pattern by the headache patients. The field study may be followed by an interview study to reflect on the usage behavior. Also, the HeadacheTracker may allow the users

to explore the effect of combining any number of potential headache triggers. In addition, machine learning algorithms can be used to develop a model that learns from collected data and predicts probability of headaches given different scenarios (i.e. probability of having headache if there is an increase in "red wine" intake).

Another future work direction can be designing for the needs of headache patients who are experienced in data collection and seeking deeper insights about their headache triggers. As I have found in my requirements elicitation study, headache patients who are already experienced in data collection, have a better knowledge of their own headache triggers. These patients want to know more specifics about the headache triggers. More specifically, experienced users want to experiment with perceived headache triggers to understand how those triggers are actually triggering the onset of their headaches. For example, if coffee is considered as a headache trigger, the headache patient who is experienced in data collection would want to compare two time periods by changing frequency and amount of coffee intake for those time periods to understand how he/she should control his/her coffee intake.

6.3 Conclusion

The main goal of my research was to help chronic headache patients by developing a self-monitoring application that allows them to collect and reflect on the collected headache data to identify potential headache triggers. I designed and evaluated the HeadacheTracker application to meet my research goal. In Chapter 1, I asked two research questions to explore the design of the data collection and the data visualization interfaces of the HeadacheTracker application based on the needs of the headache patients. In Chapter 3, I analyzed the headache patients' needs and elicited a set of requirements for designing the HeadacheTracker application. To realize the value and appropriateness of the elicited requirements, I designed the HeadacheTracker application and

evaluated its usability. Based on the usability evaluation results, I can assert that the application is designed to fit into a headache patient's daily life with respect to headache data collection. The application also provides visual insights about the potential headache triggers and headache trends to increase the headache patient's knowledge about his/her headache triggers. The insights also enable the headache patient to generate data-driven conjectures about his/her headache triggers. That means, HeadacheTracker can help headache patients identify probable headache triggers based on interactive and visual data analysis. While the HeadacheTracker is not commercial-ready, the usage scenarios and the evaluation results presented in this thesis are encouraging for further research in the area. The design of the HeadacheTracker application may help inform the design of smartphone based self-monitoring applications for chronic diseases.

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APPENDIX A: CONSENT FORM FOR ETHICS

This appendix contains the consent forms used for the requirements elicitation and evaluation study presented in this thesis.

UNIVERSITY OF CALGARY

Title of Project:

Personal Health Informatics Tool for Chronic Headache Patients.

Name of Researcher, Faculty, Department, Telephone & Email:

S. M. Waliur Rahman MSc Student, Computer Science, University of Calgary [redacted]	Dr. Frank Maurer Professor, Computer Science, University of Calgary [redacted]
Dr. Anthony Tang Assistant Professor, Computer Science, University of Calgary [redacted]	Dr. William Jeptha Davenport Medical Director of CHAMP, South Health Campus [redacted]

Sponsor:

Not Applicable.

This consent form, a copy of which has been given to you, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

Purpose of the Study

The purpose of this interview study is to understand what kinds of features are important for a smartphone-based application that helps track headache conditions effectively. We are interested in learning how an interactive mobile application can help chronic headache patients to track and monitor headache conditions. If you are interested we invite you to participate in this study.

What would I have to do?

If you agree to participate in this study, you will be asked to participate in the following different research activities:

1. You will be contacted through email or phone to schedule a face to face interview session with the researchers. The interview will be 20-30 minutes.

2. In the interview session, first you will be asked few questions about your previous experience about using headache diary. The interview will be audiotaped.

3. Next, you will be shown paper based prototypes of the proposed application interface to discuss and collect your feedback on the interface designs. If you have any new idea, you may use papers to draw your thoughts. During this part, a researcher will observe, take notes, and videotape your responses when you provide your feedback. Only your hands and fingers interacting with the prototypes will be videotaped. Identifiable features like face or any other

identifiable feature will not be videotaped.

4. You may wish to participate in the next phase of the study to evaluate the developed smartphone application. You can mention your willingness to participate in the next phase in page 2 of this consent form.

What are the risks?

There are no known harms or risks associated to the participation in this study.

Will I benefit if I take part?

If you agree to participate in this study there may or may not be a direct benefit to you. If you are in the study because you have been identified as having chronic headache, your condition may be improved during the study but there is no guarantee that this research will help you. The information we get from this study may help us to understand tool support requirements and design better applications in the future for patients with chronic headaches.

Do I Have to Participate?

Your participation in this research is voluntary. You may refuse to participate altogether or in part. You may withdraw from participation in this study at any time without penalty or loss of benefits. To withdraw from the study you can simply call or email the concerned researcher.

What else does my participation involve?

You should be a current patient of Calgary Headache Assessment and Management Program at South Health Campus. You should also have general idea of how to use smartphone features.

Will I be paid for participating or do I have to pay for anything?

You will not be paid for participating but you will be reimbursed CAD 20 as compensation for parking during each study participation. You do not need to pay for anything.

Will my records be kept private?

Your records and feedback from the interview sessions will be kept with the researchers during the study period. No other personal identifying information (such as name) will be collected.

In order to better communicate the results of this research in written publications and presentations, it may be helpful to share video (or still photographs from the video) of you in an interview or participatory design. If you grant us permission to share video (or still photographs from the video) of yourself in an interview, in written publications or presentations of this research, there is a chance that your hands and fingers while drawing prototypes will be shown. Identifiable features like face or any other identifiable feature will not be videotaped. We will never, however, reveal your name in association with your image.

Please note that, where intended reporting of photographed or videotaped images includes public display, the researchers will have no control over any future use by others who may copy the images and repost them in different formats or contexts, including online.

Please indicate your preference to the following statements:

I grant permission to be audio taped: Yes: ___ No: ___
I grant permission to be videotaped: Yes: ___ No: ___

I grant permission to be contacted through email or phone for next phase of the study: Yes: ___ No: ___
Email:
Phone:

What Happens to the Information I Provide?

Participation in this research is completely voluntary and confidential. You are free to discontinue participation at any time during the study. Any information you contribute up to the point at which you choose to discontinue your participation will be retained and used in the study. No one except the researchers will be allowed to see or hear any personally-identifiable information unless you have given permission for us to share video or photographs of you in our interview, in publications or presentations of this research. The audio/video tapes, questionnaires and interview data will be kept on password-protected university computers or in a locked cabinet only accessible by the researchers. The data will be stored for five years and can be used in future studies, after which it will be permanently erased.

Signatures

Your signature on this form indicates that 1) you understand to your satisfaction the information provided to you about your participation in this research project, and 2) you agree to participate in the research project.

In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information throughout your participation.

Participant's Name: (please print) _____

Participant's Signature: _____ Date: _____

Researcher's Name: (please print) _____

Researcher's Signature: _____ Date: _____

Witness' Name: (please print) _____

Witness' Signature: _____ Date: _____

Questions/Concerns

If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Dr. William Jeptha Davenport,
Medical Director, Calgary Headache Assessment and Management Program
[redacted]

If you have any questions concerning your rights as a possible participant in this research, please contact the Chair, Conjoint Health Research Ethics Board, University of Calgary at 403-220-7990.

A copy of this consent form has been given to you to keep for your records and reference. The investigator has kept a copy of the consent form.

UNIVERSITY OF CALGARY

Title of Project:

Personal Health Informatics Tool for Chronic Headache Patients.

Name of Researcher, Faculty, Department, Telephone & Email:

S. M. Waliur Rahman MSc Student, Computer Science, University of Calgary [redacted]	Dr. Frank Maurer Professor, Computer Science, University of Calgary [redacted]
Dr. Anthony Tang Assistant Professor, Computer Science, University of Calgary [redacted]	Dr. William Jeptha Davenport Medical Director of CHAMP, South Health Campus [redacted]

Sponsor:

Not Applicable.

This consent form, a copy of which has been given to you, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

Purpose of the Study

The purpose of this study is to evaluate the effectiveness of a smartphone application to track and monitor chronic headache conditions. We are interested in learning how an interactive mobile application can help chronic headache patients to track and monitor headache conditions. If you are interested we invite you to participate in this study.

What would I have to do?

If you agree to participate in this study, you will be asked to participate in the following different research activities:

1. You will be contacted through email or phone to schedule a face to face application demo and entry interview session with the researchers. The session will be 20-30 minutes.

2. In the above mentioned session, first the researchers will demonstrate how to use the application using different features and functionalities. Then, you will be given a few tasks using the application and will be asked to perform the tasks in front of the researcher. The researcher will observe and take notes while you perform the tasks and at the end you will be required to answer few questions about your first experience of using the application. Your responses will be recorded.

3. Next, you will download the application into your smartphone and will use the application for 16 weeks to track and monitor your headache data. We will monitor which features of the application you use during this time and would like to know your experience about those used features. During the usage period you will need to answer survey

questions at different times as required by the application which will give you opportunity to share your experience about the application use. The survey will be done through your phone and not in person.

4. In the last week of application usage period, you will be contacted again through email or phone for an exit interview (15 minutes) where you will be asked questions to evaluate the features and functionalities of the application that you have used for past few weeks. The researcher will observe, take notes and audiotape your responses when you provide feedback.

What are the risks?

There are no known harms or risks associated to the participation in this study. However, please do not use the smartphone application during driving or walking to avoid unwanted distractions and incidents.

Will I benefit if I take part?

If you agree to participate in this study there may or may not be a direct benefit to you. If you are in the study because you have been identified as having chronic headache, your condition may be improved during the study but there is no guarantee that this research will help you. The information we get from this study may help us to understand tool support requirements and design better applications in the future for patients with chronic headaches.

Do I Have to Participate?

Your participation in this research is voluntary. You may refuse to participate altogether or in part. You may withdraw from participation in this study at any time without penalty or loss of benefits. To withdraw from the study you can simply call or email the concerned researcher.

What else does my participation involve?

You should be a current patient of Calgary Headache Assessment and Management Program at South Health Campus. You should also own a smartphone (e.g. iPhone, Android etc) and have general idea of how to use smartphone features. Your smartphone should have internet connection.

Will I be paid for participating or do I have to pay for anything?

You will not be paid for participating but you will be reimbursed CAD 20 as compensation for parking during each study participation. You do not need to pay for anything.

Will my records be kept private?

Your records and feedback from the interview sessions and the usage period will be kept with the researchers during the study period. No other personal identifying information (such as name) will be collected.

Please indicate your preference to the following statements:

I grant permission to be audio taped:	Yes: ___ No: ___
I grant permission to be contacted through email or phone during the study:	Yes: ___ No: ___ Email: Phone:

What Happens to the Information I Provide?

Participation in this research is completely voluntary and confidential. You are free to discontinue participation at any time during the study. Any information you contribute up to the point at which you choose to discontinue your participation will be retained and used in the study. No one except the researchers will be allowed to see or hear any personally-identifiable information unless you have given permission for us to share video or photographs of you in our interview, in publications or presentations of this research. The audio/video tapes, questionnaires and interview data will be kept on password-protected university computers or in a locked cabinet only accessible by the researchers. The data will be stored for five years and can be used in future studies, after which it will be permanently erased.

Signatures

Your signature on this form indicates that 1) you understand to your satisfaction the information provided to you about your participation in this research project, and 2) you agree to participate in the research project.

In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information throughout your participation.

Participant's Name: (please print) _____

Participant's Signature: _____ Date: _____

Researcher's Name: (please print) _____

Researcher's Signature: _____ Date: _____

Witness' Name: (please print) _____

Witness' Signature: _____ Date: _____

Questions/Concerns

If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Dr. William Jeptha Davenport,
Medical Director, Calgary Headache Assessment and Management Program
[redacted]

If you have any questions concerning your rights as a possible participant in this research, please contact the Chair, Conjoint Health Research Ethics Board, University of Calgary at 403-220-7990.

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APPENDIX B: OPEN CODE CATEGORIES

Category	Codes in category
different knowledge level about own triggers 3 codes applied to 6 paragraphs	concentration on chinook 1x concentration on food triggers 1x speculation of headache triggers 5x
ensuring quality data collection 7 codes applied to 9 paragraphs	data with appropriate measurement 2x list of headache symptoms is useful 2x mobile diary for timely data collection 1x option to add notes to a data 2x quick and easy data entry 4x recording accurate timings of events or activities 1x scheduled reminder for data entry 4x
headache triggers 3 codes applied to 3 paragraphs	bright light, high noise, stress can be triggers 1x chinook can be trigger 1x different foods can be triggers 1x
interactive visualization 9 codes applied to 8 paragraphs	aesthetic visual objects for interaction 1x data visualization to see average headache severity trend 1x data visualization to see relation of headache with menstrual cycle 1x different colors to represent headache condition 1x easily understandable charts 1x existing charts are too generic 1x headache condition summary in main page of app 1x maximum 3 trigger factors comparison in a graph 2x reviewing mobile graphs with detail data and explanations on larger screen 1x
record keeping for self and clinician 12 codes applied to 14 paragraphs	keeping diary for clinician's review 3x mobile app should have all options of champ diary 1x recording everyday diet 1x recording exercise 1x recording headache severity level at different times of the day 3x recording medication effectiveness 3x recording multiple types of headaches at the same time 1x recording side effects of treatment 1x recording symptoms to identify medication need 1x recording treatment or medication 6x

Category	Codes in category
self-monitoring of headaches 3 codes applied to 7 paragraphs	analyzing variance in continuous headaches 1x comparison of low severity headache period with high severity headache period 2x data analysis to avoid headache triggers 4x
self-understanding of triggers 10 codes applied to 24 paragraphs	combining different data sources is inconvenient 1x combining paper diary and app data for deeper analysis 1x comparing collected data with baseline data 1x correlating trigger factor with headache frequency 8x data analysis is time consuming 1x data analysis to identify triggers 7x data visualization to identify triggers 6x iterative data analysis and experimentation to identify triggers 6x potential triggers should be highlighted in visualization of daily events or activities 1x review of 24 hours of past events or activities 1x
uncategorized codes 3 codes applied to 3 paragraphs	help required on how it works 2x schedule reminder for daily activities (meal, exercise etc) 1x simple tips for relaxation 1x

APPENDIX C: DATA MODELS (SCHEMA)

Headache Schema

```
headache : mongoose.Schema({
    userID : "string",
    headacheID : "string",
    startTime : "string",
    startTimeAMPM : "string",
    startDate : "string",
    endTime : "string",
    endTimeAMPM : "string",
    endDate : "string",
    severity : [{recordTime : "string", recordTimeAMPM :
"string", recordDate : "string", severityLevel : "number"}],
    disability : {recordDate : "string", disabilityLevel :
"number"},
    painArea : {tmj : "boolean", sinus : "boolean", cluster :
"boolean", tension : "boolean", migraine : "boolean", neck :
"boolean"},
    painNature : "string",
    painSymptom : {noSymptom:"boolean", lightSensitivity :
"boolean", soundSensitivity: "boolean", nasalCongestion :
"boolean",
        nauseaCondition:"boolean", depressedMood:"boolean",
smellSensitivity:"boolean", feelAnxious:"boolean",
otherSymptom:"boolean"},
    userLocation : "string",
    painNote : "string",
    lastSaved : "string",
    confirmed : "boolean"

})
```

Food Schema

```
food : mongoose.Schema({
    userID : "string",
    foodTrackDate : "string",
    foodTrackTime : "string",
    foodName : "string"
})
```

Drink Schema

```
drink : mongoose.Schema({
    userID : "string",
    drinkTrackDate : "string",
    drinkTrackTime : "string",
    drinkName : "string"

})
```

Exercise Schema

```
exercise : mongoose.Schema({
    userID : "string",
    exerciseTrackDate : "string",
    exerciseTrackTime : "string",
    exerName : "string",
    exerStatus : "string"
})
```

Sleep Schema

```
sleep : mongoose.Schema({
    userID : "string",
    sleepTrackDate : "string",
    sleepTrackTime : "string",
    sleepStatus : "string"
})
```

Stress Schema

```
stress : mongoose.Schema({
    userID : "string",
    stressTrackDate : "string",
    stressTrackTime : "string",
    stressLevel : "string"
})
```

Menstruation Schema

```
period : mongoose.Schema({
    userID : "string",
    periodTrackDate : "string",
    periodTrackTime : "string",
    periodStatus : "string"
})
```

Medication Schema

```
medication : mongoose.Schema({
    userID : "string",
    medicationTrackDate : "string",
    medicationTrackTime : "string",
    medicationType : "string",
    medicationName : "string",
    medicationQuantity: "string"
})
```

Weather Schema

```
weather : mongoose.Schema({
    DateTime : "string",
    Year : "number",
    Month : "number",
    Day : "number",
    Time : "string",
    Temp : "number",
    RelHum : "number",
    WindSpd : "number",
    StnPress : "number"

})
```

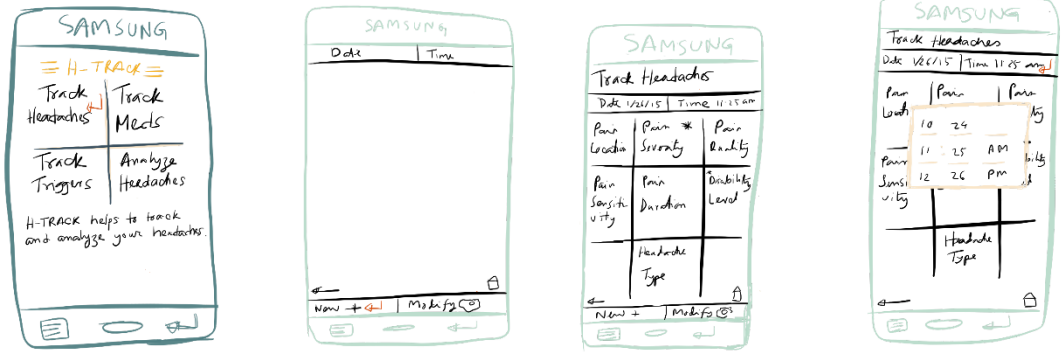
Timebucket Schema

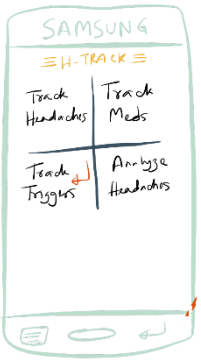
```
timebucket : mongoose.Schema({
    userID : "string",
    month: "number",
    date: "string",
    time: "string",
    segment: "string",
    item: "string",
    environment: {temp: "string", hum: "string", wind :
"string", press: "string"}
})
```

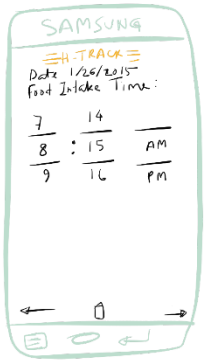
APPENDIX D: LOW-FIDELITY PROTOTYPES

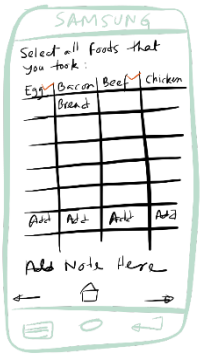
Data Collection Interfaces: Set 1 (From Left to Right)

Data Collection Interfaces: Set 2 (From Left to Right)









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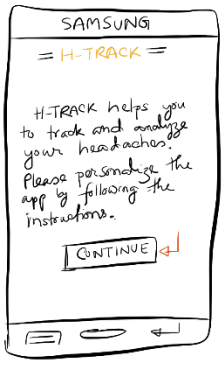

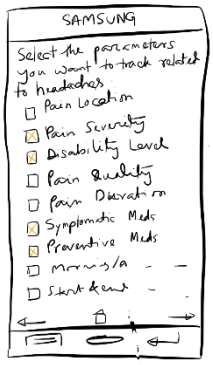

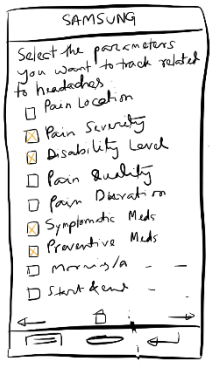

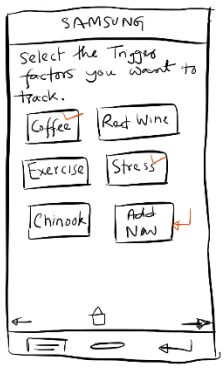

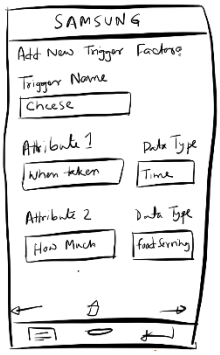

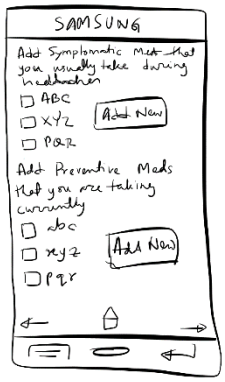

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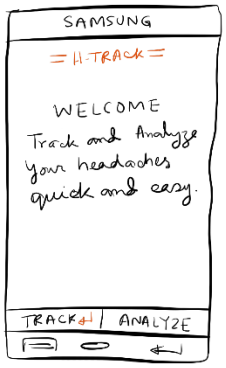

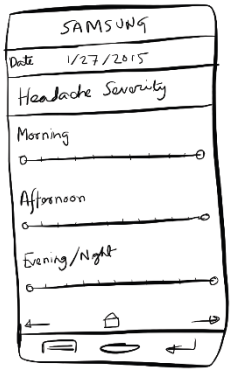

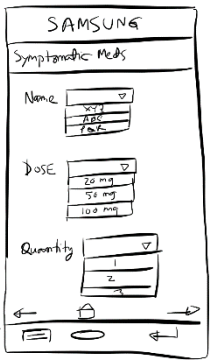

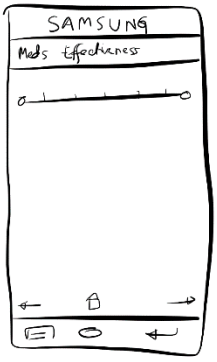

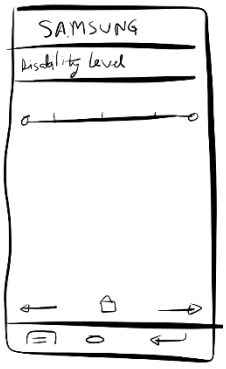

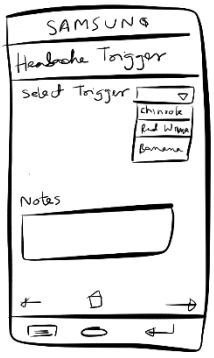

Data Collection Interfaces: Set 5 (From Left to Right)