HeadacheCoach: Towards headache prevention by sensing and making sense of personal lifestyle data

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Abstract. Estimates are that almost half of the world's population has an active primary headache disorder, i.e. with no illness as an underlying cause. These can start manifesting in early adulthood and can last until the rest of the sufferer's life. Most specialists concur that sudden changes in daily lifestyle, such are sleep rhythm, nutrition behavior or stress experience, can be valid triggers for headache sufferers. Health care professionals recommend leading a diary to self-monitor personal headache triggers in order to learn to avoid headache attacks. However, making sense out of this data is difficult. Despite existing smartphone approaches in literature that have evaluated behavior change support systems for headaches, they have failed to provide appropriate feedback on the collected daily data to showcase what causes or prevents an individual's headache attacks. In this paper, we present HeadacheCoach, a smartphone app that tracks headache-triggering lifestyle data and headache attacks on a daily basis and propose a mixed-method approach to examine which feedback method(s) can strive the behavior change most in order to prevent future headache attacks.

Keywords: mHealth, self-tracking, personalization, feedback.

1 Introduction & Related Work

According to Stovner et al. [1], 46% of the world's adult population has an active primary headache disorder, i.e. a headache disorder not caused by an underlying disease or condition such as a brain tumor or an aneurism. Primary headaches often manifest in early adulthood and can last until the rest of the sufferer's life [2].

Most specialists concur that sudden changes in lifestyle such as a change in sleep rhythm (falling asleep, going to bed late), in eating behavior (skipped meals, fasting), or in experienced stress (no stress during weekend) can be valid triggers for some headache sufferers [3, 4]. Headache sufferers are often convinced of their trigger factors, with (bad) food and weather often being considered one [5]. Interestingly, people suffering from migraines are often found to be completely unaware of what triggers their headache attacks [6]. To identify the actual impact of each headache and to

evaluate the effectiveness of a treatment option, health care professionals often recommend patients to self-monitor their headache triggers, such are pain intensity, medication intake, symptoms, and triggers [7, 8], within diaries [7, 9].

Smartphones have emerged as one of the leading self-monitoring tools for many health conditions, including headache attacks [10]. In an analysis of 38 commercially available headache diary apps, Hundert et al. [7] discovered that only 18% of the apps were created with scientific or clinical headache expertise and that none of the apps monitored data on days when no headache events occurred. They recommend offering scientifically validated apps to the broad public and to involve headache experts in the development of those apps. Huguet et al. [11] created myWireless, an iPhone-based headache diary application. It allowed users to track information on both headache and headache-free days, was customizable to the individual user's needs and was developed with the help of headache experts. Its main problem was finding a sufficient balance between providing headache sufferers with great insights into their condition while imposing minimum effort and time maintaining the diary. This aligns with the work of Park & Chen [12], who recommend future systems for people suffering from headache disorders to shift their focus from simply tracking to making sense of the data. Furthermore, there exists a lack of studies on smartphones for digitally delivered behavioral interventions for headache reduction [13].

Despite evaluating behavior change support systems for headaches, the listed smartphone approaches have failed to provide appropriate feedback on the collected daily data to showcase what causes or prevents an individual's headache attacks. We present HeadacheCoach, an Android smartphone prototype tracking potential headache triggers and presenting various feedback methods to examine what causes or prevents individual's headache attacks. The idea of HeadacheCoach evolved from interviews with three neurological and headache experts from the Universitätsklinikum Großhadern in Munich. Besides the interviews, we conducted a literature review to identify relevant headache-causing lifestyle triggers. Afterwards, we integrated several external data sources in order to track a set of the found triggers. Based on the tracked data, we conceptualized three feedback methods that differ in their presentation form, content and action degree. Finally, we propose an evaluation method to find the most effective method in supporting a behavior change in preventing headaches. Through self-monitoring of lifestyle data and headache attacks, as well as personalized recommendations, we expect that HeadacheCoach will contribute in reducing the severity and frequency of headaches and thus foster a long-term behavioral change in an individual's lifestyle.

2 HeadacheCoach

HeadacheCoach is an Android prototype that lets users self-monitor their headache attacks and collect lifestyle data from already existing apps and services on a daily basis, even on days when no headache attack occurs. This way, HeadacheCoach examines the relations between the collected lifestyle data and the (lack of) headache

attacks, with the final aim of helping the user to reflect on her headache triggering behavior and accordingly act on it.

2.1 Sensing Headache Triggers

One of the most often discussed topics in combination with primary headaches are their triggers. Triggers are endogenous or exogenous factors in a patient's environment that temporarily increase the probability or intensity of a headache attack for this particular patient [4, 14].

We matched a selected set of identified trigger factors with apps or devices that can be integrated into the HeadacheCoach app. We integrated the two health centers S Health and Google Fit, a weather API called WeatherLib, and the Android smartphone sensors into the HeadacheCoach app.

Sleep [12, 6] is either manually tracked via S Health or automatically via the 'Sleep as Android' app. Once connected to S Health, it automatically transmits the gathered sleep data to S Health, thereby making it accessible to HeadacheCoach. Automated tracking through 'Sleep as Android', offers more detailed insights into sleep, including precise times for falling asleep and waking up and the different sleep stages that are experienced during the night.

Dietary trigger factors, such are certain foods [12, 6], dehydration [12] and meal intake regularity [12, 14], are user-reported within S Health. Additionally, there are external apps available that solely focus on logging food, water and alcohol intake. For example, 'Lifesum', can be connected to S Health or Google Fit, leading to HeadacheCoach using its data. However, there is no possibility so far of tracking perceived hunger levels with these services, which we consider for future versions of HeadacheCoach.

Lack of physical activity or exhaustion afterwards [15] can also have a headache triggering effect. Some forms of physical activity can both be automatically tracked within Google Fit and S Health. S Health has a 'Detect workouts' feature that automatically logs any walking, running, cycling, and hiking activity that lasts longer than 10 minutes [16]. Google Fit offers a similar feature, 'Activity detection', that automatically detects walking, running, and biking activities [17]. Other activities can be logged manually in both S Health and Google Fit. Additionally, both apps count user's daily taken steps.

For tracking weather triggers [12, 14, 18], an external API called WeatherLib was integrated into HeadacheCoach. Based on user's current location, it fetches the current weather status, including outside humidity, precipitation, pressure, temperature and wind. Lastly, Android phones implement several environmental sensors, spanning from ambient temperature and relative humidity to light and pressure. These can keep track of some environmental factors influencing headaches [12, 14]. However, not all Android-based phones have the same number and implementation of its sensors.

Unfortunately, the first version of HeadacheCoach still lacks the feature of tracking some other triggers. For example, stress [12, 6, 18] could be potentially tracked via app usage patterns [19] or via a constant heart rate feed [20] by including an external heart rate sensor. There are apps available on Google Play that track menstruation [12, 18], but none of them currently offer an API or an integration into one of the

health centers. Furthermore, it might be interesting to understand user's environment by analyzing audio recordings [21]. Additionally, the calendar app of the smartphone could be queried to identify certain situations after which headache attacks are more likely to occur. Finally, the users themselves could manually track trigger factors within the app and select what they think might be the cause of their current headache in the 'New Headache' section of the app. For an overview of all implemented tracking methods, please refer to **Table 1**.

Table 1. A selected set of found triggers (Categories and Trigger) and the implemented tracking method in HeadacheCoach

Category	Trigger	How to Track on Android
Sleep	Sleep deprivation	S Health manual tracking 'Sleep as Android' in conjunction with S Health
	Excess sleep	S Health manual tracking 'Sleep as Android' in conjunction with S Health
	Sleep pattern	'Sleep as Android' in conjunction with S Health
	Sleep disturbance	'Sleep as Android' in conjunction with S Health
	Fatigue	Implied information from S Health manual tracking Implied information from 'Sleep as Android' in conjunction with S Health
Diet	Specific food or ingredients	S Health manual tracking 'Lifesum' in conjunction with S Health 'Lifesum' in conjunction with Google Fit S Health manual tracking 'Lifesum' in conjunction with S Health or Google Fit
	Alcohol	
	Dehydration	
	Hunger	
	Fasting or missing meals	
Physical activity	Physical inactivity	S Health automatic tracking Google Fit automatic tracking
Environmental factors	Weather	API
	Heat	Indoor - Android ambient temperature sensor Outdoor - API
	Cold	
	Air quality	
	Sunlight	API Android light sensor
	Bright light	Android light sensor
	Fluorescent lights	Android light sensor

Besides sensing headache triggers, HeadacheCoach offers a feature to manually track the appearance of a new headache attack. The feature includes tracking information about the headache's timespan, medicine taken to mitigate the headache and the accompanying symptoms to the headache. As a self-monitoring component, HeadacheCoach provides an overview of the previous tracked headaches, either as a list of the headache entries, a calendric overview or graphical representation.

However, dealing with headache attacks has to go beyond straight forwarded tracking of lifestyle data and headache attacks, by rather providing a valuable, personalized insight into the collected data of triggers and headaches and possible correlations among them [12], including the detection of trigger patterns in headache-free days. This brings us to the point of feedback, which we explain in the next section.

2.2 Feedback Methods

Any personal information collected from external sources about an individual's behavior and deliberately delivered with the goal of promoting behavior change is commonly illustrated as personalized feedback ([22], p.36, as cited in [23]). Feedback has indicated to increase the efficacy of self-monitoring for changing behavior [23].

We implemented three distinct, personalized feedback methods that differ in their (1) *form*, i.e. whether they are textual or graphical representations [24], (2) *action mechanism,* i.e. how feedback influences the behavior change process and (3) *content* [25]. If feedback content points out to a risk or problem, it is referred to as *risk or problem* based. The *current status* based content presents the current status of the user with regard to her collected lifestyle data. Finally, content that offers dynamic actions that affect the behavior change are referred to as *change based*. The three developed feedback methods are encapsulated into three separate tabs within the home screen and named "Triggers", "My help" and "Overview" respectively (**Fig. 1**).

The „Triggers" feedback method provides a *risk-based* insight into the causes of headaches. We formed the feedback as a list of simple text messages, demonstrating at what probability and under what triggers a headache attack could appear. The mechanism of action of the feedback is twofold, by providing the user with *critical risk* and *protective* information with an *educational* purpose.

The „My help" feedback showcases a list of concrete actions the user can immediately do in order to prevent future headache attacks. This way the feedback offers concrete *change* measures. As a mechanism of action, we provide support by giving concrete handling actions. The actions are stylized with an icon depicting the action and a textual explanation of the action with its time unit.

Finally, the „Overview" feedback method showcases a *graphical* representation of the *current state* of triggers, based on the work of [26]. The green hoop pictures the optimal range of six trigger categories (i.e. Exercise, Sleep, Water Intake, Food, Caffeine and Steps). A red point within the inner circle denotes a trigger shortage. Conversely, a red point outside the hoop denotes an excess of trigger. A black point within the hoop presents a trigger within the optimal range. By zooming into a specific category, the user can get an insight of the single triggers within the categories and

their current numerical value. By *increasing engagement in the information,* we offer an *educational* action mechanism.

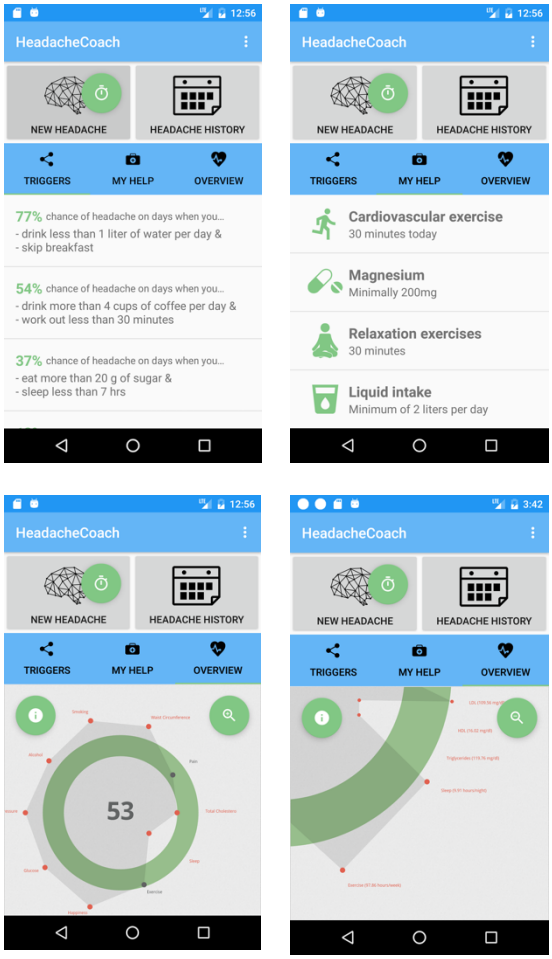

Fig. 1. The proposed feedback methods (clockwise): 'Triggers', 'My Help', 'Overview' (Details) and 'Overview'

3 Proposed Mixed-Method Evaluation Approach

We expect to conduct an experimental study in the summer 2017, lasting for three months. We propose a between subject design for the study, with the feedback method being the independent variable, i.e. either Triggers, MyHelp or Overview. Besides measuring the comparative effects between the feedback methods, we want to examine the effects when the methods are combined, i.e., when both Triggers and Overview are offered, or in case all three feedback methods are included. We therefore

deduce nine intervention study groups, with the control-group having no feedback on the sensed data.

Data analysis points will follow after one and three months. All usage data with the app will be logged and stored to a server. We intend to measure the self-reported volume of headache attacks at the beginning of the study, after one and three months, as well as the engagement with the app continually.

In order to not only evaluate whether a behavior change has occurred, but also *why* [27] it occurred, we intend to conduct interviews with the study participants during the study. In that way, we hope to gather valuable insights and further improvements for the feedback methods and HeadacheCoach in general.

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