

On assumed usefulness of wearable sensors in early recognition of migraine attacks perceived by patients

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Abstract

This study analysed how migraine patients assume to improve their daily life if wearable sensors provide them pre-warnings of approaching or impending migraine attacks. The study analysed the use of new technology in identifying pre-symptoms in migraine patients using the Technology Acceptance Model (TAM) focusing on the assumed usefulness of a wearable device. The study added understanding of getting migraine patients to accept smart technology to support their own treatments. The results were drawn from a sample of altogether 582 migraine patients with or without an aura. The difference between migraine with aura and without aura is that migraine with aura precedes physical symptoms like visual disturbances, numbness, and difficulty in speech, while there are no pre-symptoms in migraine without aura. The assumed wearable device (WBAN) notifies, however, the bio-signals of an oncoming migraine attack.

Due to current achievements with available digitalised tools to monitor health and wellbeing, also self-care is benefiting. Pre-migraine symptoms are among the biggest challenges in identifying migraine. Noting this, our study addressed the value of wearable sensors in early recognition of migraine attacks.

Keywords: migraine, self-care, sensor networks, digitalisation

Introduction

The purpose of the study was to find out how the interviewees assume to improve their daily life if wearable sensors provide them with a pre-warning of an oncoming migraine attack. The goal of this study was pursued by understanding the benefits the users expect from the wearable devices.

New wireless technology creates opportunities for monitoring vital signs with wearable biomedical sensors [1]. This concept used in medicine has spread to patient care, where new wearable computing is supposed to improve migraine patient's quality of life and life management by providing the patients with an early warning of an oncoming attack [2,3].

In wireless sensors, the idea is to avoid a wired connection to the storage unit. The aim is to give the patient freedom of movement and to improve the quality of life in which he can carry out normal activities but is constantly under constant supervision [4,5]. In addition, mobility improves quality of life, and the patients can continue their normal daily routines [1] or go to work [3].

User acceptance and user-friendliness issues of wearable devices for self-tracking patients' vital signals have interested researchers already earlier [6–10]. Fensli et al. [1] presented a generic sensor acceptance model describing the factors determining the acceptance of health-related wearable sensors. Pagán et al. studied potential bio-signals for an early detection of migraine attacks focusing on EKG [11], and Huttunen et al. [5] analysed migraine patients' opinions on the physical appearances of sensors and their locations on the body. The prior studies leave, however, a research gap on what are the patients' expectations for the benefits of wearable sensors that can predict oncoming migraine attacks.

In this qualitative study, we focused on the assumed benefits of wearable devices detecting pre-symptoms of migraine from the perspective of migraine patients. Studying the assumed usefulness without an existing technical solution was initiated by the Finnish Migraine Association, and further motivated by earlier studies pointing out the need of an early participation of the targeted users in the development of services and applications [12]. To study the assumed usefulness, we applied the Technology Acceptance Model TAM [13] as a framework. The research problem was answered with the help of a questionnaire and an interview. Altogether, 582 patients answered the questionnaire, and 12 persons were interviewed. The data were analysed with the help of NVivo 12 tools. Our research results show that migraine patients were able to identify eight benefits they expect from wearable sensors and self-tracking, taking medication on time being the most important benefit. That finding sets a key constraint for the selection of the bio-signals and design of the sensors that are, however, subjects for future studies.

Background and related work

Evaluating technology acceptance

One of the best known and most widely used models for explaining technology acceptance is the Technology Acceptance Model, called TAM [7,13,14]. A human bases her actions on her beliefs and attitudes, so the model aims to determine which factors influence end-users' acceptance of technology [13,15]. TAM [13] groups the factors affecting the acceptance of information technology by its potential users into two main categories, the perceived usefulness, and the perceived ease of use as shown in Figure 1.

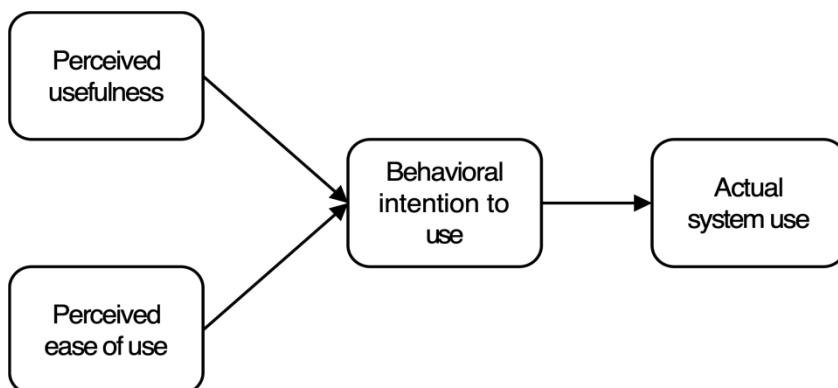


Figure 1. 1.Basic TAM by Davis [13].

Davis [13] grounded his model on a pre-test and a field study conducted among 120 information technology professionals using two sample systems of its time. Based on the pre-test he proposed such factors as effectiveness, job performance, quality of work, and eleven others for the ‘perceived usefulness’, and controllable, cumbersome, frustrating, and 13 others for the ‘perceived ease of use’. All the factors of the perceived usefulness and ease of use presented by Davis [13] can be ranked as generic characteristics of information systems in professional use, without a focus to specific application types or user groups.

TAM can be used to explain the use of technology and to anticipate the intention to use [16]. Perceived usefulness refers to whether the user considers it probable that the use of a technological application will be of benefit to his or her work. Perceived ease of use, on the other hand, means whether the user thinks the new application is easy to use [13,17]. In practice, the observed usefulness has been highlighted as the most important feature in TAM, followed by the observed ease of use [16,17].

Other studies on the deployment of new technology resulted in a unified theory of acceptance and use of technology UTAUT [18] and UTAUT2 [19], the former focusing on the technology use in the organizational contexts [18,19], and the latter expanding the original UTAUT to cover the consumers’ point of view [19].

While being broadly accepted, intensively studied, and further developed models, both TAM and UTAUT/UTAUT2 have also faced criticism [7,14,20], such as ‘perceived usefulness’ and ‘perceived ease of use’ are not in balance in case of technology for health care, ‘perceived usefulness’ having a dominating weight [7]; neither TAM nor UTAUT describe well the acceptance of technology in the health care area [9]; the value of both the TAM and the UTAUT models are affected by the mobile technology and digital services changing the way how technology is used [20].

Wearable sensors and self-tracking

Latest advances in sensor, computing and communications technologies have enabled development of a wide variety of smart devices being able to monitor various bio signals of the human body,

so called Wearable Body Area Network (WBAN) devices [21]. Broadly used application areas cover monitoring of heart, sleep, blood pressure, body temperature, oxygen saturation, blood sugar, and general activity of a human – areas where sensor technology for different body signals have been available. Movassaghi et al. [21] pointed out two main values of the use of WBAN devices – society's overall economic benefits and patients' personal benefits. Swan [22] took up the topic of patient-driven health care models, and deepened the discussion in [23] by defining a term Quantified Self as an umbrella concept for self-tracking. She pointed out the potential benefits of patient-driven health care for many aspects of the human life, including health.

Klasnaja and Pratt [24] studied technology-supported self-tracking as a means for a generic health-related behaviour change, but also pointed out its value in health care. Warraich [12] conducted a systematic literature review focusing on the use of wearable activity trackers as behavioural interventions to improve wellness of individuals and pointed out the early participation of the targeted users in the development of services and applications. Kari et al. [25] referred to Warraich's [12] remarks on early user participation and different set of user requirements as one motivation of their study on understanding of how people use and perceive wellness technology in their everyday lives. Huttunen and Halonen [3] focused on technology-supported self-tracking in case of migraine by studying the bio-signals preferred by migraine patients for predicting an incoming migraine attack.

For migraine attack recognition, solutions based on sleep monitoring with Empatica E4 sensor [26–28] or ambulatory data [11] have also been studied.

Migraine

Migraine is the most common wide-ranging neurological disease [29], and attacks last for 4–72 hours and change rapidly [30]. Migraine is treated with two different medications: preventive everyday medication and acute medication when symptoms begin [31]. Acute medication should be taken before the headache to get the best response to migraine treatment [32].

Due to the economic costs caused by migraine, solutions for migraine self-care should be developed [33]. The development of a new medical wearable device for migraine patients should consider bio-signals of sleep quality, stress level, sleep rhythm, energy consumption, pulse, and blood pressure [3]. Bio-signals provide useful information for humans on physiological changes, and migraine patients are interested in using smart devices in their daily lives to monitor their everyday living [34], and disease prediction [5]. The information provided by the sensors helps patients in their own care, provides feedback and enables disease monitoring [3,24,34].

Research method

The Finnish Migraine Association initiated this study on the assumed usefulness of wearable sensors though no actual sensor solution was available to be deployed in the study. We focused on the assumed benefits and usefulness of wearable sensors in early recognition of migraine attacks, without focusing on the ease of use or any specific WBAN technology or solution.

As a theoretical framework of our study, we opted TAM, despite the critics targeted to the models [7,9,14,20], because the Finnish Migraine Association's initiative did not fix any theoretical framework, and studying usefulness in terms of assumed

benefits will widen the body of knowledge of technology acceptance independently of any models. As summarised in Section 2.2, perceived usefulness seems to dominate over the perceived ease of use and, thus, omitting the ease of use because of missing sensor solutions would not decrease the value of our study.

In this study, we focused on the migraine patients with pre-symptoms. Using TAM [13] as a starting point, we explored the potential usefulness of wearable sensor in early recognition of migraine attacks to find answer to the following research question:

In which ways do the interviewees assume to improve their daily life if wearable sensors provide them with a pre-warning of an oncoming migraine attack?

Kitchenham et al. [35] recommend using literature studies for identifying relevant literature for the “related research” section in other primary studies and as a baseline for empirical research of various kinds. To support the empirical part of our study, to understand the relevance of “Technology Acceptance Model in Healthcare”, and to explore the latest studies on wearable sensors, self-tracking and self-care, a literature search was conducted following guidelines suggested by Petersen et al. [36] and Wohlin [37], resulting to total 37 publications.

To create a broad, explorative understanding, we utilised in our empirical study a qualitative method approach, combining a survey and interview methods for research data gathering [38] and a thematic synthesis for the data analysis [39].

The research data were gathered from two sources: from the answers to the open-ended questions of a survey we concluded to the mem-

bers of the Finnish Migraine Association and from an interview. The survey was conducted in autumn 2016 and the interviews in spring 2017. The survey was open for three weeks and it covered whole Finland. In all, 582 migraine patients answered to our survey. The survey consisted of 30 structured and open-ended questions, out of which the answers to one open-ended questions were used in this study.

Additionally, we conducted interviews of 12 local migraine patients who were contacted over the social media and were willing to be interviewed. The interviews were carried out with an interview schema that covered the same topics as the survey. In both patient sets, the sample patients had migraine with an aura, without an aura, or both.

The answers to the open-ended questions of the survey were copied without modifications to a single MsWord document for the subsequent analysis. The interviews were semi-structured [40], and they addressed the migraine type and reasons why migraine patients would want to use variable sensors for identifying migraine attacks. The interview data was added to the MsWord document created from the survey answers.

To analyse the data, we utilised the thematic synthesis [39,41]. The synthesis was carried out with NVivo12 tool. Our thematic synthesis combined inductive and deductive coding, figuring out an initial set of codes and defining new ones when new topics emerge from the research data during the coding process [39].

The deductive approach started with five initial codes selected to cover a-priori identified reasons for wearable sensor utilisation. During the coding, additional three inductive-type codes were identified. The resulting eight codes are listed in Table 1, together with the number of occurrences found

from the research data. While continuing the thematic synthesis, we identified three second-order themes, combining the codes, as shown in Table 2.

Results

The value of the usefulness-related themes for the migraine patients was evaluated by the number of

their occurrences in the research data, as shown in Table 1 and Table 2.

Figure 2 visualises the results. The sizes of the bubbles and the percentage figures reflect the number of occurrences compared to the total amount of occurrences, 673.

Table 1. Identified first-order themes (codes).

	Theme	Description	Occurrences
1	Attack identification	Better attack identification but just own feelings	121
2	Differential diagnostics	Separating migraine attacks from headaches caused by other reasons	15
3	Understanding of own migraine	Improved recognition of body reactions in case of migraine attacks	104
4	Private life control	How an early warning will help in organizing the private life	99
5	Work life control	How an early warning will help in organizing the work life	46
6	Pre-symptom recognition	Identifying pre-symptoms of migraine attacks	27
7	Migraine attack beginning time	Earlier recognition of forthcoming migraine attacks	41
8	Medicine in time	Improved usage of medicines against forthcoming migraine attacks	220

Table 2. Identified second-order themes (codes).

	Theme	Description	Occurrences
1	Patients' awareness of the sickness	How the new technology improves patients' own understanding of the changing nature of migraine, combines first-order themes 1, 2, and 3	240
2	Patients' coping with the difficulties caused by the sickness, life control	How the new technology may help migraine patients' possibilities to manage the stress and problems caused by the sickness, combines first-order themes 4 and 5	145
3	Patients' situational awareness	How the new technology improves migraine patients' own understanding of the time-wise progress of an attack, combines first-order themes 6, 7, and 8	288

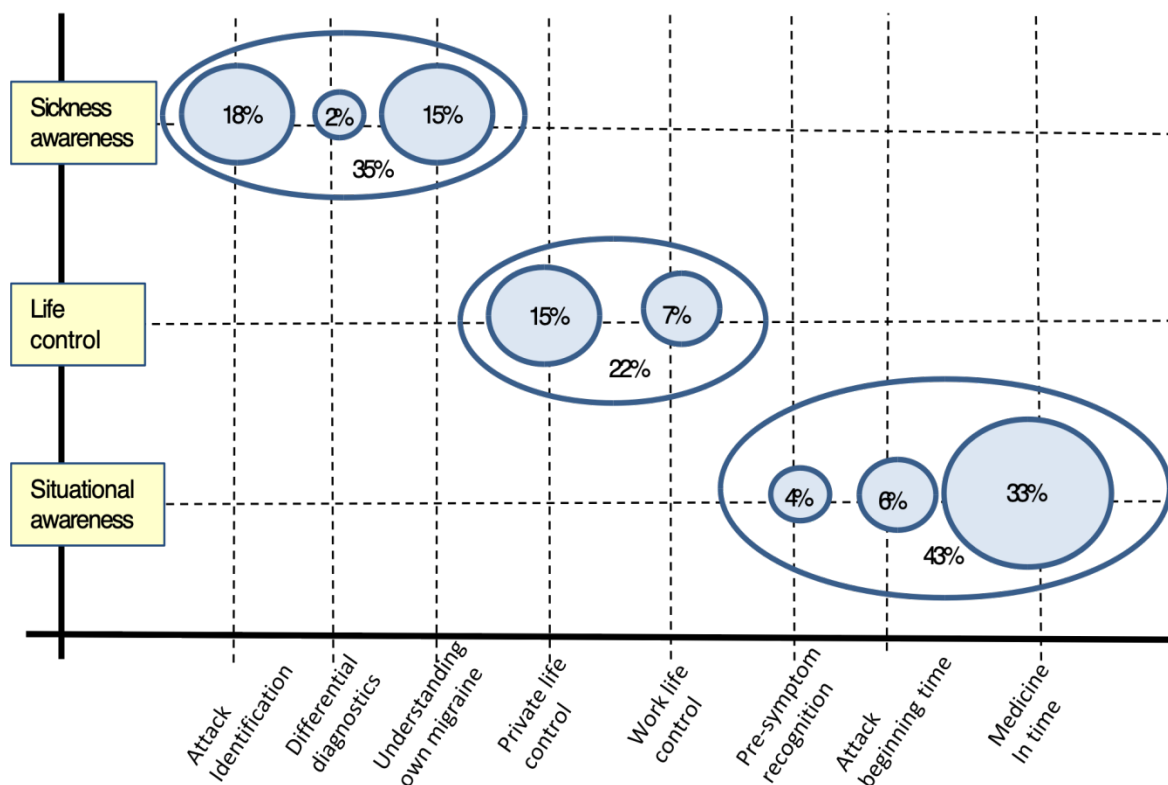


Figure 2. Results of the thematic synthesis.

As shown in Table 2 and Figure 2, the codes of all three second-order themes were broadly brought up in the open-ended questions of the survey and in the interview data. As migraine is a disease causing the patients difficulties in daily life, both privately and professionally [2,34], it was interesting that patients' life control got in the thematic synthesis a lower number of occurrences than the themes related to the patients' situational and general awareness of their disease. We may assume that the topics covered by the situational awareness and sickness awareness are to an extend prerequisites to a patients' abilities get along to their migraine in the daily life and were, thus, more frequently noted as potential benefits of the wearable sensor technology.

The more detailed codes reveal that right-timed medication taking was considered as the most important potential benefit. It got alone 220 occurrences of total 673 ones (33% of all occurrences). That indicates that right-timed taking of medication play a key role in how the patients master the disease and is the area where wearable sensors and self-tracking give the biggest benefits. A detail highlighting the importance of medication is, that the codes pointing out the recognition of pre-symptoms and the beginning of an attack without including medication taking got together only 68 occurrences being 10% of all occurrences.

Interestingly, being able to control the private life regardless of the migraine got twice that many occurrences than that of the work life, indicating

that the attitudes towards employees suffering from migraine attacks is understanding and supportive among Finnish employers and colleagues, while living the daily private life is more hampered by migraine attacks.

Another interesting detail to point out was the low occurrence count of the differential diagnostics such as the patients' abilities to recognise forthcoming migraine attacks from headaches caused by some other reasons. It got the lowest number of occurrences among all eight codes identified in the synthesis, only 15 occurrences, 2% of all occurrences. That indicates that the patients tend to know which headache is caused by migraine attacks and which not.

Discussion

The goal and purpose of the study was to determine the assumed benefits of a wearable device in identifying the pre-symptoms of migraine. The models of technology acceptance and use, such as TAM and UTAUT/UTAUT2 have been used as the framework when studying new technology in many application areas, including the health care [7–9,42]. The goal of this study was pursued by understanding how migraine patients assume to improve their daily life if wearable sensors give them a pre-warning of an ongoing migraine attack, using the findings of prior research [12,25] as a framework.

When comparing the findings of our study to the original components of the perceived usefulness [13], one notices that our findings are very specific for the migraine and the patients' ways to cope with it, while the original components of the perceived usefulness address the aspects of a professional's work around the timeframe of the publication of Davis' article.

As Carlsson and Walden in [20] noted the developments in the technology and digital services have changed the ways how technology is used – from professional, work-related use to a part of everyday life with a broad palette of beneficial services, leading to components of the perceived usefulness that are specific for the technology and the context of its usage [7,9,20]. From that perspective our study is in line with the prior studies and expands the body of knowledge of both technology acceptance and deployment of wearable sensors in health care.

This study confirmed that it is important to study the assumed usability of novel technology that will provide new value and arouse the user's desire to use the technology before the final devices or applications are available, as pointed out in the prior literature [12,25,34].

Migraine is treated with two different medications: preventive everyday medication and acute medication when symptoms begin [31]. In our previous research, we studied the collection of bio-signal data for early detection of the migraine attacks [28]. In this study, the most important feature of wearable sensors to the migraine patients was that the device directs the medication to be taken on time. The result is in line with the findings of earlier studies pointing out the early detection of abnormal conditions as a key value of wearable sensors [21]. Well in line with the prior literature are also other findings of our study, such as control of the private and work life improving the quality of life [21] and leading to empowerment and responsibility taking [23]. Our findings indicate that migraine, being a chronic sickness with a periodic nature, fits well for self-monitoring enabling the patients' own sickness management in the daily life [23,24].

Our main finding, supporting the medication taken on time, sets a key constraint for the development of a multipurpose WBAN – its ability to predict migraine attacks in a timeframe that is equal or longer than the pharmacokinetic times of acute migraine attack medications. Among the variety of migraine medications, triptans are the recommended primary treatment for severe or disabling migraine in Finland (<https://www.kaypahoito.fi/>). Triptans are available in form of tablets, injection pens and nasal sprays. The pharmacokinetic characteristics vary depending on the triptan in question and the intake mechanisms, leading to effect latencies between 15 min to 120 min, with a typical maximum serum concentration time 60-90 min [30,43] (<https://pharmacafennica.fi/>).

We summarise our results in the following three statements by answering the research question: In which ways do the interviewees assume to improve their daily life if wearable sensors provide them with a pre-warning of a coming migraine attack?

1. The potential usefulness of wearable sensors is related to three main aspects of a migraine patients' life, sickness awareness, situational awareness, and life control.
2. The situational awareness dominates over the other two aspects.
3. Being able to take the medication on time is the most important individual benefit out of eight identified benefits of wearable sensors.

Conclusions and future research

We conducted a qualitative study on the potential usefulness of wearable sensors in self-care of migraine patients. The aim was to explore the expectations migraine patients set on wearable sensors

monitoring oncoming migraine attacks. Our findings fell in three main categories, sickness awareness, situational awareness, and control of life, highlighting the importance of the medication on time. They bring novel knowledge about wearable sensors in the context of migraine. The findings of our study also expand the body of knowledge concerning TAM [13].

Our study was focused on the usefulness side of TAM. Utilising wearable sensors include – besides the development of bio-signal-specific sensors – also development of application systems that provide the users with full-scale services on top of the sensors, such as user interfaces, attack logs, or medication reminders and diaries. Thus, future studies on the factors of the ease of use will bring necessary knowledge for figuring out the functionality, user interfaces, and other application-level aspects necessary when developing full systems for self-tracking [14]. Broadening the future studies with the user-related factors, like gender, age, and experience presented in UTAUT/UTAUT2 [18,19] models would further broaden the necessary understanding.

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Conflict of interest

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