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Taxonomy of health IT and medication adherence

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KEYWORDS
Health IT;
Medication adherence;
Taxonomy;
Non-adherence factors;
eHealth;
Medication compliance

Abstract

Background: Patients' failure to take medication as prescribed – poor medication adherence – is a well-known issue. Health information technology (IT) presents itself as a promising approach to tackle poor medication adherence.
Objectives: To deepen the understanding of what features health IT offers and how these address poor medication adherence, we examine existing health IT targeting medication adherence.
Methods: Building on extant literature, we follow a systematic approach for taxonomy development in information systems to build a taxonomy of health IT focusing on medication adherence.
Results: Health IT offers various promising ways to address poor medication adherence. Overall, we map 16 different types of health IT offerings on 7 different dimensions. The principal results are that health IT focusing on medication adherence should be developed in a patient-centered way because medication adherence is predominantly a matter of the patient and that mobile technologies are a seminal driver for health IT offerings focusing on medication adherence. Finally, the taxonomy identifies the core impacts of health IT on medication adherence.
Conclusion: The taxonomy establishes an overview of current health IT offerings targeting medication adherence, offers insights into untapped potential for health IT, and yields valuable insights for health policy and technology. Future efforts must, however, address how to continuously motivate patients and how to better integrate and combine health IT offerings to unfold the full potential of health IT for addressing poor medication adherence.
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Introduction

Back in the days of Hippocrates, one of the limiting factors for achieving satisfactory medical outcomes was patients' failure to adhere to physicians' advice; today, this circumstance remains unchanged [1–3]. Numerous interventions have been developed to address poor medication adherence

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and resulting health risks. During the last decade, the number of internet-based interventions focusing on medication adherence substantially increased [4]. Internet-based interventions, or health information technology (IT) in general, have the potential for individual treatment tailored specifically to the needs of the individual patient; several health IT offerings target poor medication adherence in different ways. However, the plentitude and diversity of available health IT makes it hard to ascertain what features health IT actually offers and how these address poor medication adherence.

In order to make the interrelationship of health IT and medication adherence more graspable, the objective of our research is to foster understanding what features health IT offers and how these address poor medication adherence. To achieve the research objective, we develop a taxonomy of health IT targeting medication adherence. Taxonomies group objects of interest by common characteristics and simultaneously separate them by dissimilar characteristics. Hence, taxonomies highlight commonalities and differences of objects of interest. Therefore, taxonomies are a powerful tool for structuring complex problem areas and organizing knowledge [5]. With respect to health IT targeting medication adherence, a taxonomy is useful to establish an overview and to foster understanding of how features of health IT address poor medication adherence, by consolidating extant knowledge and establishing a common foundation. The taxonomy can be used to guide development of health IT aiming to improve medication adherence and to identify hitherto untapped potential for new interventions as well as pregnant future research directions. Consequently, a taxonomy of health IT targeting medication adherence yields valuable insights for health policy and technology, for example, with respect to health funding, education, and technology development projects.

Background

Medication adherence

To ensure a clear understanding of the term medication adherence (hereinafter called 'adherence') within this work, we adopt the definition by Cramer et al.: Adherence "refers to the act of conforming to the recommendations made by the provider with respect to timing, dosage, and frequency of medication taking" [6].

Adherence is a complex phenomenon. Despite the large number of studies in this area, consensus about factors that control adherence or interventions that address poor adherence is absent [7,8]. It is however clear that poor adherence correlates with an increase in morbidity and mortality [7]. This emphasizes the importance of proper adherence as following treatment regimens could decrease mortality and morbidity rates. Other studies on this topic show that poor adherence results in further negative consequences, for example, higher probability of mistakes in diagnosis and treatment, increased medical expenses, as well as dissatisfaction and problems in the relationship of medical professionals and patients [6,7]. In addition, poor adherence compromises effectiveness of treatment in long-term therapies. Even the best treatments are likely to fail if patients do not adhere to their regimens. The main consequence is that patients' diseases may not be mended or cured at all [8]. In the end, patients' behavior determines success or failure of treatment [9].

Many patients have difficulties with adherence at some point during treatment [10]. The World Health Organization (WHO) has classified a number of non-adherence factors into five areas, social/economic, condition-related, therapy-related, health care team and system-related, and patient-related, as shown in Figure 1 [8]. A recent study provides support for the non-adherence factors such as treatment-related complexity [11]. Diabetes treatment serves as an illustrative example for complexity of treatment. Depending on the treatment, a diabetes patient has to take 3–10 pills a day, that is, 21–70 pills a week, 84–280 pills a month or 1008–3360 pills a year. Besides treatment-related factors, a variety of other non-adherence factors must be taken into account to assure good adherence [8,11]. Proper physician-patient communication (see Figure 1) plays, for instance, an important part [9]; thus, physicians should explain the benefits and side effects of medications and propose alternative therapies [1].

Design of individual intervention strategies addressing poor adherence must take certain goals into account, which vary for each intervention strategy and each patient [7]. Extant research on conventional interventions targeting

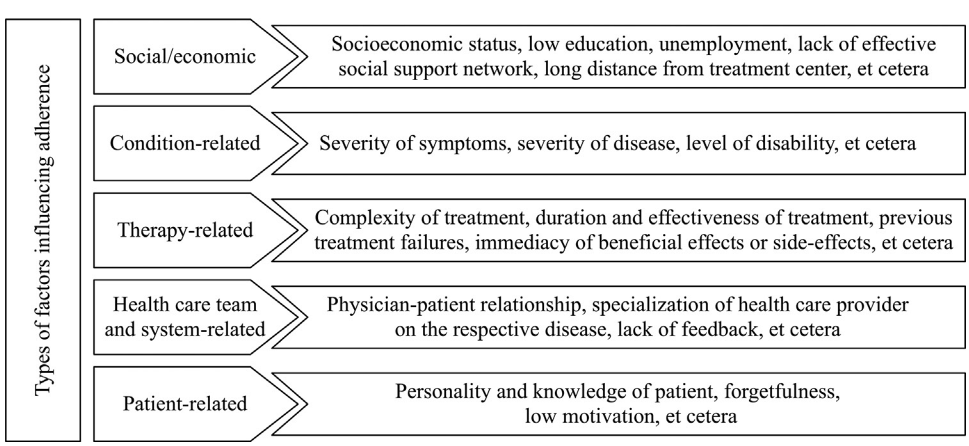

Figure 1 Non-adherence factors (adapted from [8]).

poor adherence focuses predominantly on changing patients' behavior [8]. According to several reviews on adherence, behavioral interventions are however not effective on its own, whereas interventions using a combination of various strategies (i.e., patient education, changing behavioral skills, self-rewards, improved social support, and telephone follow-up) are more effective and result in better treatment outcomes [10,12,13]. Yet, even the most-effective conventional interventions have shown no significant impact on adherence in long-term treatments [14]. Health IT seems like a promising technology offering many ways to improve on conventional intervention strategies and to facilitate new approaches [15].

Health IT

There are many terms used synonymously to describe the same concept of delivering health care through information technology (e.g., eHealth, telemedicine, telehealth, health information and communication technology) [16,17]. In this paper, these concepts are collectively referred to as 'health IT'. Health IT is commonly defined as the "application of information processing involving both computer hardware and software that deals with the storage, retrieval, sharing, and use of health care information, data, and knowledge for communication and decision making" [18]. It is further understood as a state-of-mind, a way of thinking, or an attitude, contributing to improvement of health care by using information and communication technology [19]. Health IT is a vehicle supporting and facilitating intervention strategies to tackle poor adherence. 'Information' plays a central role in health IT and no other sector is as dependent on information as health care [15]. However, the complexity of information increases with the degree of cross-linkages between the various actors in the health care domain (e.g., service providers, citizens, patients, hospitals, industry) and through the tailored display of information. Only through information and communication technologies, these challenges will be manageable in the future [15,20,21].

Health IT is not a rigid construct and takes various forms. Often-quoted examples of health IT are [15]: support of cooperation between two institutions, immediate supply of information in emergency situations, obtainment of second opinions in rural areas, and home care. Figure 2 shows an excerpt of common, available health IT. Health IT is gaining in importance, especially, in the form of mobile devices and services [22]. Health devices are distinguished on the basis of their mobility (i.e., mobile or stationary) [21]. The majority of the public in the US possesses a mobile phone and can theoretically request health information from almost everywhere [15,23,24]. Furthermore, the majority of people in the US wants electronic access to their personal health information [25], which can be achieved easily through mobile devices. Moreover, physicians gain a better overview of their patients' disease development once the data is transmitted to a server and automatically analyzed [26]. In the context of adherence, health IT supports patients in various situations. One of the most common health behavior patients perform daily is the use of medication [23]. Health IT reminds patients to take their medications, recognize pills, order refills, etc.

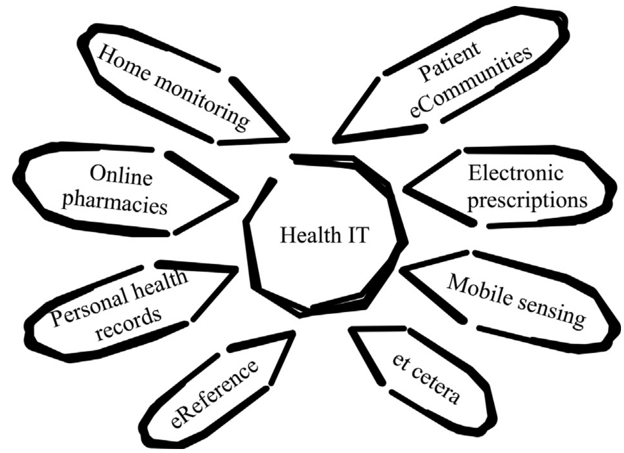

Figure 2 Excerpt of available health IT.

Methodology

We develop a taxonomy of health IT focusing on adherence, which groups health IT offerings based on their common characteristics. The developed taxonomy establishes an overview, structures domain knowledge, and pinpoints untapped potential for new offerings [5]. To identify health IT offerings targeting adherence, we look at extant research focusing on adherence issues and health IT published in journals and conferences focusing on computer science, medicine, information systems, and health IT. We build the taxonomy following the method of Nickerson et al. [5] for taxonomy development in information systems. The method proved to be useful because it is systematic, straightforward, and provides guidance during the taxonomy development process [27,28]. Figure 3 shows a flowchart of the taxonomy development method.

A taxonomy is defined as a set of dimensions [5]. Each dimension is comprised of at least two characteristics. The characteristics of a dimension have to be "mutually exclusive and collectively exhaustive" [5] so that exactly one characteristic of each dimension can be assigned to every classified object. As illustrated in Figure 3, the method consists of three major steps. At the beginning a meta-characteristic is chosen from which all other characteristics are derived. Selection of a meta-characteristic fosters consistency throughout taxonomy development. Afterwards, ending conditions are specified. The taxonomy is created and refined in iterative passes until the ending conditions are met. For each pass, an empirical-to-conceptual or conceptual-to-empirical approach is chosen. The empirical-to-conceptual approach starts with empirical instances and derives dimensions and characteristics from these instances. The conceptual-to-empirical approach derives dimensions and characteristics through a comparison of the current taxa in the taxonomy. Initially, the decision which approach to use depends on the amount of information available on the objects under study [5]: if sufficient information on the problem domain is available, starting with the empirical-to-conceptual approach is recommended. If only little information is available, starting with the conceptual-to-empirical approach will be more promising.

Our selection of health IT offerings for the taxonomy is constrained to health IT targeting adherence. With respect to adherence, patients play a major role because "drugs don't

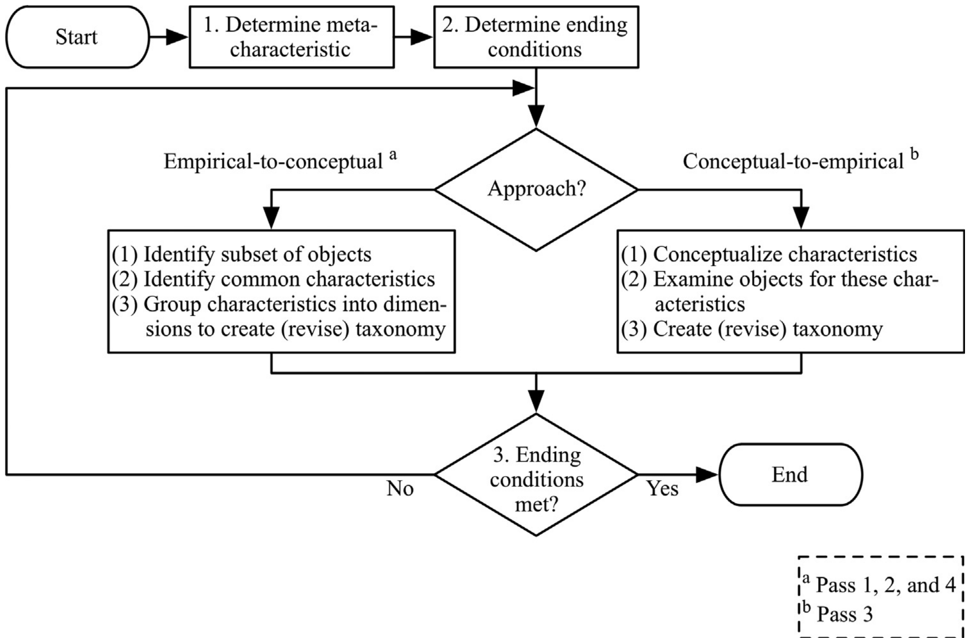

Figure 3 Flowchart of the taxonomy development method (adapted from [5]).

work in patients who don't take them" [29]. Furthermore, "patients' personal attributes probably have the strongest influence on adherence" [30]. If patients are not motivated to address poor adherence, changes in state-of-health are unlikely. Due to the fact that "adherence is primarily in the domain of the patient" [1], the use of health IT to tackle poor adherence must be patient-centered. Hence, the meta-characteristic for the taxonomy is the patient-centered use of health IT. Since mobile technologies are increasingly integrated into health care [22], the initial identification of health IT offerings for the taxonomy was based on a review of about 14,000 mobile apps supporting patients' medication use, which was conducted by Bailey et al. [23]. To close potentially remaining gaps during the iterative taxonomy development passes, we either added additional health IT offerings to the taxonomy or derived more dimensions from the health IT offerings already in the taxonomy. Health IT offerings were independently assessed by two researchers. In case of any discrepancies, consensus was reached through group discussion with a third researcher. Common subjective ending conditions (i.e., the taxonomy is concise, robust, comprehensive, extendible, and explanatory) and common objective ending conditions (i.e., no new dimensions were added in the last iteration and no additional health IT offerings need to be examined) were applied [5]. In order to ensure the coverage of common, available health IT offerings in the taxonomy, we tested the taxonomy against a data set of about 24,000 mHealth apps identified in a study by Dehling et al. [31].

Results

First iteration

We used the empirical-to-conceptual approach for the initial iteration since sufficient information on health IT targeting adherence is available. Based on a review conducted by Bailey et al. [23] seven health IT offerings were identified. Two dimensions differentiate these health IT offerings: 'interaction' (active or passive patient interaction) and 'health information storage' (storage or no storage of health information). Medication histories, for example, let patients create and manage medication logs through active interaction and store health information. Active interaction is present whenever a health IT offering requires users to provide input in order to use the main functionality offered. The health IT offerings are: 'eReference' [23,32], which provides information to improve patients' understanding of their medications and treatments. In general, patients use eReferences as a first point of contact in self-help. 'Medication reminder' [23,33], which supports patients to take their medications at predetermined times. Such reminders include audible or visual aids as well as text messages. 'Refill reminder' [23], which notifies patients when a medication refill is necessary. 'Order refills' [23] are designed to order medication refills online in a simple and easy way. After order confirmation, medication is dispatched by a pharmacist. 'Medication history' [23] allows patients to create and manage their medication history (e.g., intake and dosage history) for tracking purposes. 'Identify pills' [23] applications identify pills based on visual appearance (i.e., imprint, color, and shape). 'Pharmacy locator' [23] finds pharmacies near the patient based on GPS position or ZIP code. Table 1 shows the combined results of all four iterations in detail and specifies which health IT offering was added in which iteration.

Second iteration

Since there were only health IT offerings in the taxonomy that target single users, we identified potential group user offerings in order to close this gap. Thus, we followed the empirical-to-conceptual approach for the second iteration. Two dimensions differentiate these health IT offerings: 'ubiquity' (mobile or stationary usage) and 'multiplicity' (individual or group experience). Home monitoring, for

Table 1 Taxonomy of health IT addressing medication adherence.

Health IT offerings	Interaction		Health information storage		Ubiquity		Multiplicity		Human in-volvement		Feedback		Person-alization	
	A[a]	P[b]	S[c]	NS[d]	M[e]	S[f]	I[g]	G[h]	I[i]	NI[j]	F[k]	NF[l]	P[m]	G[n]
eReference[o]		X		X	X		X			X		X		X
Medication reminder[o]		X	X		X		X			X	X		X	
Refill reminder[o]		X	X		X		X			X	X		X	
Order refills[o]	X		X		X		X		X			X	X	
Medication history[o]	X		X		X		X			X	X		X	
Identify pills[o]		X		X	X		X			X		X		X
Pharmacy locator[o]	X			X	X		X			X		X		X
Automated consulting[p]	X			X	X		X			X	X		X	
Automated dispensing[p]	X		X			X		X		X		X	X	
Electronic medication monitoring[p]		X	X		X		X		X		X			X
Home monitoring[p]		X	X			X		X	X		X		X	
Online support community[p]	X		X		X			X	X		X			X
Videoconferencing[q]	X			X	X		X		X		X			X
Wireless body sensor network[q]	X		X		X		X			X	X			X
Personal health record[q]	X		X		X		X			X	X		X	
Electronic prescription[q]		X	X		X		X		X			X		X

Legend of abbreviations:

[a]A=Active interaction: Users are actively involved in data input (e.g., selection of medications during the ordering process).

[b]P=Passive interaction: Users are not continuously involved in data input (e.g., home monitoring must be initially set up but there is no continuous need for interaction).

[c]S=Storage of health information: Users' information are stored by the health IT offering.

[d]NS=No storage of health information: Users' information are not stored by the health IT offering.

[e]M=Mobile usage: The health IT offering can be used everywhere.

[f]S=Stationary usage: The health IT offering is bound to a specific environment.

[g]I=Individual experience: The health IT offering is used by a single user.

[h]G=Group experience: Functionality of the health IT offering leverages interaction of multiple users.

[i]I=Human involvement: Service provision requires input from medical professionals or other experts.

[j]NI=No human involvement: Users do not depend on input from medical professionals or other experts.

[k]F=Feedback: The health IT offering provides health-related feedback to the user (e.g., feedback by other users or experts in online support communities on health-related topics).

[l]NF=No feedback: The health IT offering does not provide health-related feedback to the user (e.g., no health-related feedback while locating a pharmacy).

[m]P=Personalization: Users can tailor the health IT offering to their needs and preferences.

[n]G=Generalization: Users cannot tailor the health IT offering to their needs and preferences.

[o]Health IT added in the first iteration.

[p]Health IT added in the second iteration.

[q]Health IT added in the fourth iteration.

example, is bound to the home environment (i.e., stationary use) of the patient and targets multiple users (i.e., all residents). The five additional offerings are 'automated consulting' [34], which informs patients via telephone about imminent appointments and delivers automated health consulting. Patients respond to the system using keypad entry or speech recognition. 'Automated dispensing' [35] distributes medications by automatically composing the right dosage of medication for the patients. Automated dispensing machines are accessible in public areas (e.g., corridor of a hospital) by many patients. 'Electronic medication monitoring' [34,36,37] provides information on daily intake and consumption patterns. An electronic monitoring device is attached to a medication container that records the date and time the container is opened. After return of the container, physicians analyze and interpret the data. 'Home monitoring' [34,35] uses different technologies (e.g., sensors, RFID, and networks) embedded in the home environment to monitor patients' daily living activities. Similar to electronic medication monitoring, the collected data can be analyzed by the physician to inform treatment. 'Online support communities' [38] are web-based communities (e.g., forums) for patients with the aim to share experiences, find other patients with similar diseases, and learn from aggregated reports of other patients to achieve better health outcomes.

Third iteration

For the third iteration, we used the conceptual-to-empirical approach to derive more dimensions from the current health IT offerings in the taxonomy: some offerings include

Table 2 Core impacts of health IT on medication adherence and challenges addressed.

Non-adherence factors	Health IT dimensions						
	Interaction	Health information storage	Ubiquity	Multiplicity	Human involvement	Feedback	Personalization
Social/ economic			Long distance from treatment center	Lack of effective social support network			
Condition-related	Level of disability						
Therapy-related		Complexity of treatment				Duration and effectiveness of treatment	Complexity of treatment
Health care team and system-related					Poor physician-patient relationship	Lack of feedback	
Patient-related				Low adherence motivation		Forgetting to take medication	Tailoring to patients' needs

human involvement, whereas others do not. The 'human involvement' dimension assesses whether another health care actor (e.g., a physician or a pharmacist) needs to interact with health IT offerings to achieve full operability (human involvement or no human involvement). Some offerings deliver feedback to patients through automation or human actors. The 'feedback' dimension classifies whether health IT offerings provide feedback to the patient or not (feedback or no feedback). Feedback is for example given in the form of information on the patient or treatment progress. Some offerings allow for personalization by tailoring specific elements of the health IT offering (e.g., content), which helps to tailor offered functionality specifically to patient needs and preferences. The 'personalization' dimension assesses personalization of health IT offerings (personalization or generalization). Order refills need, for example, a physician for a valid prescription and a pharmacist for order execution, whereas a medication or refill reminder does not depend on human involvement. Automated dispensing is personalized in terms of composing the right medication and dosage for the patient, but does not provide any feedback to them.

Fourth iteration

In order to ensure the coverage of common, available health IT in the taxonomy, we used the empirical-to-conceptual approach for the fourth iteration to add additional health IT offerings to the taxonomy. Thus, we tested our taxonomy against a data set of about 24,000 mHealth apps identified in a study by Dehling et al. [31]. The four new health IT offerings added in this iteration yield no new dimensions. The offerings are 'videoconferencing' [39-42], which connects patient and physician via video with the aim to create an in-person session, comparable with a face-to-face conversation. Similar to online support communities, patients express themselves, share their experience, and learn from their physician in a one-to-one consultation. A 'wireless body sensor network' (WBSN) [26,31,43,44] provides information based on sensors measuring physiological functions. WBSNs typically measure a wide range of physiological parameters, such as blood glucose, oxygen levels, pulse rate, and blood pressure. A 'personal health record' [31,45] provides patients with the ability to manage their health information (e.g., medical diagnoses, medications, test results) in a private and confidential environment. The patient controls access to the health information and decides what information to share with other actors (e.g., physicians). 'Electronic prescription' [1] replaces traditional handwritten prescriptions. Electronic prescription enables paperless handling of prescriptions by electronically transmitting prescriptions issued by physicians.

After the fourth iteration, subjective and objective ending conditions are met: the taxonomy is concise because the number of dimensions used is meaningful [5]. In addition, the taxonomy is robust because enough dimensions exist to differentiate among health IT offerings. Furthermore, the taxonomy is explanatory since the dimensions provide useful explanations but do not describe the health IT offerings in complete detail. Moreover, the taxonomy is extendible since, by design, new dimensions and characteristics can be easily added. With the four additional health IT offerings added in this iteration, the taxonomy is also comprehensive. Finally, no new dimensions were identified in this iteration. Therefore, all ending conditions are met. The final taxonomy of health IT addressing adherence, depicted in Table 1, is given by the following formula:

T={Interaction (active, passive),
Health information storage (storing, non-storing),
Ubiquity (mobile, stationary),
Multiplicity (individual, group),

Human involvement (involvement, non-involvement),
Feedback (feedback, non-feedback),
Personalization (personalized, generalized)}.

Discussion

Principal results

The developed taxonomy establishes an overview of existing health IT targeting adherence (see Table 1). The core impacts of health IT on adherence are summarized in Table 2. Each of the five non-adherence factors (see Figure 1) are addressed by at least one of the seven identified health IT dimensions (see Table 1). The socio-economic factor is addressed by the dimensions of ubiquity and multiplicity: patients using mHealth devices and services can overcome long distances to treatment centers or high transport costs. Furthermore, patients can improve their social support network by participating in group user activities offered by health IT. The condition-related factor is addressed by the dimension of interaction: patients with disabilities can benefit from health IT with passive interaction since there is no need for continuous interaction after the initial setup. The therapy-related factor is addressed by the dimensions of health information storage, feedback, and personalization: patients' treatment can increase in complexity, for example, due to the intake of different medications; health IT supports patients in tracking their medication intake. Based on the stored data, medical professionals can get an overview of patients' current treatment regimens and give them custom feedback regarding their treatment, if required. Moreover, health IT can be tailored to the needs of individual patients as well as their treatments to increase treatment effectiveness. The health care team and system-related factor is addressed by the dimensions of human involvement and feedback: the medical expert can improve his relationship with the patient through continuous involvement. The involvement can take various forms, for example, feedback on patients' adherence performance. The patient-related factor is addressed by the dimensions of multiplicity, feedback, and personalization: low patient motivation can promote poor adherence; group user activities, however, can foster motivation and support adherence. Another reason for poor adherence is patients' forgetfulness in taking medication, which can be improved by feedback, for example, in form of reminders. Furthermore, the offered services can be tailored specifically to patients' needs and preferences.

Some health IT offerings share identical characteristics in all dimensions. While they offer the same basic functionality, they focus on different application purposes. For example, medication reminder and refill reminder serve as a reminder; yet, their application differs: a medication reminder focuses on medication intake and a refill reminder focuses on order refills. A core finding is that communication technology in the form of mobile devices and services is gaining in importance: almost all health IT offerings identified can be usedmobile ($n_{\text{mobile}}=14$; $n_{\text{stationary}}=2$). Future offerings will continue to be developed for mobile use since the technologies that underlie mobile devices are becoming more powerful and cheaper [22]. Potential use cases are the use of health IT offerings at work or on vacation.

Patients use the majority of health IT offerings as individual users ($n_{\text{individual}}=13$; $n_{\text{group}}=3$). There is potential for new offerings that provide group user experiences leveraging support of the social environment. Group user experiences could lead to higher motivation and promote better health outcomes [46]. The numbers of health IT offerings in the taxonomy that are personalized and generalized are equal ($n_{\text{personalized}}=8$; $n_{\text{generalized}}=8$). This indicates that both types are of value and implies that personalized as well as generalized offerings should be considered in future developments. More health IT offerings require an active interaction ($n_{\text{active}}=9$; $n_{\text{passive}}=7$). Hence, there are opportunities for the development of passive offerings, which reduce the probability of incorrect input and missing entries caused by forgetfulness. Two-thirds of health IT offerings store health information ($n_{\text{storing}}=11$; $n_{\text{non-storing}}=5$), which is, for example, useful for tracking purposes. Due to the fact that information privacy is becoming more and more important, providers of health IT offerings must, however, ensure proper privacy protection [47,48]. This will reduce the uncertainty and reluctance of patients and lead to better adoption of health IT offerings [49].

Only one third of health IT offerings require human involvement ($n_{\text{involvement}}=6$; $n_{\text{non-involvement}}=10$). Patients use the majority of health IT offerings on their own without having to wait for the response of another person. This is particularly relevant in the domain of health care since patients' suffering should be alleviated quickly. In addition, absence of human involvement reduces the cost for service provision. Yet, it is not possible to automate all services provided by health IT offerings, and quality as well as reliability concerns may necessitate human involvement. The core focus of health IT is to complement services offered by health care professionals rather than to substitute them. There are more health IT offerings providing users with feedback ($n_{\text{feedback}}=10$) than offerings not providing feedback ($n_{\text{non-feedback}}=6$). Patients obtaining feedback from health IT offerings are enabled to develop a better understanding of their state of health [24]. Future offerings could, thus, benefit from including feedback mechanisms so that patients can reflect on their behavior and, if necessary, adjust it.

The taxonomy yields implications for development and enhancement of pertinent health policy and technology. First, since mobile devices and services are gaining in importance, health IT will become more relevant in different environments. Patients' home and work environments serve, for instance, as a good example for use of health IT. Since some patients live and work in rural areas where physicians are scarce, compared with urban areas, health IT offers potential to overcome long distances. Further benefits of health IT are the continuous care and the seamless integration into patients' home and work environments. Funding for health IT projects targeting rural, home, and workplace environments could stimulate adaption and prove particularly effective. Second, many health IT offerings in the taxonomy require active user interaction ($n_{\text{active}}=9$) and only some depend on involvement of medical professionals ($n_{\text{involvement}}=6$). Thus, it is possible that incorrect health information is communicated. Educational programs could promote the importance of quality and correct communication of health information. Furthermore, since two-thirds ($n_{storing}=11$) of health IT offerings in our taxonomy store health information, education is necessary to continuously emphasize and inform all stakeholders how to protect users' health information from theft and misuse. Third, besides furthering technological and educational agendas, health IT could benefit from research funding on topics like feedback or motivational aspects in order to incorporate this knowledge in extant health IT and foster development of new health IT targeting adherence.

The number of possible combinations of the characteristics ($n=128$) shows that the taxonomy is not exhaustive. Combinations not listed in the taxonomy indicate potential new health IT offerings. For example, there are no offerings with the combination of passive patient interaction, storage of health information, human involvement, feedback delivery, and personalization that can be used in a mobile way and in a group. A monitoring application with the basic characteristics of home monitoring (see Table 1) could fill this gap. Such a monitoring application could, in addition, be used in a mobile way and as a group so that patients are not bound to one environment but could be ubiquitously monitored. Another potential health IT offering can be derived from videoconferencing (see Table 1). There are no offerings that focus on adherence and offer a group user experience with the characteristics of videoconferencing. A possible scenario is 'group videoconferencing' where one physician is connected to a group of patients. This health IT offering would create a group atmosphere, comparable with a face-to-face group conversation. A minor adaption of the body sensor characteristic (see Table 1) could benefit patients with disabilities: if active user interaction would be turned into passive user interaction, patients would not have to set up the health IT over and over again. This could, for example, be accomplished by continuously wearable technologies or implants [44]. Although it is possible for other researchers to use and extend the taxonomy, the number of resulting combinations will change with added or removed dimensions. However, the results indicate that health IT has potential for addressing poor adherence in various ways.

Limitations and further research

The reviews serving as foundation for our taxonomy focus on mHealth apps, which could explain why the majority of health IT offerings in our taxonomy can be used mobile. However, many health IT offerings initially developed for stationary use are being adapted for mobile use. Thus, today's health IT offerings are often simultaneously available for mobile and stationary use. Personal health records are, for instance, also available as smartphone apps by now. Health IT is undergoing changes and mobility is becoming increasingly important. It should also be noted that new health IT offerings launched during development of our taxonomy could not be considered. It could be beneficial to compare conventional adherence strategies with health IT strategies in order to learn from their differences. Our work fosters understanding of how features of health IT address non-adherence factors. It does, however, not aim to provide an analysis of efficacy and effectiveness of features of health IT available. This should be addressed in future research. In addition, patients need continuous motivation to tackle poor adherence. New strategies, such as gamification [24], are promising to help patients with staying motivated when using health IT. It could also prove useful to integrate multiple health IT offerings [50]. A well-connected health IT ecosystem will improve the utility of health IT for addressing poor adherence.

Conclusions

In a world where health costs are a growing public expense, the reported findings are of essential value. Novel technologies have been developed for addressing the prevailing problem of poor adherence. A promising approach is the use of health IT, especially, since conventional intervention strategies addressing poor adherence are reaching their limits [8]. Health IT eliminates disadvantages of conventional intervention strategies and offers new opportunities for addressing poor adherence. The developed taxonomy deepens understanding of what features are available and useful to tackle poor adherence with health IT. Moreover, the taxonomy establishes an overview of health IT targeting medication adherence, provides guidance for development and enhancement of pertinent health policy and technology, and is a powerful tool for identifying the next generations of health IT.

Author statements

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Author contribution

RM collected the data. All authors analyzed and interpreted the data, wrote the manuscript, were responsible for research concept and design as well as critical revision of the manuscript, and approved the final version.

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None.

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