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Review article

An ontology of and roadmap for mHealth research

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ABSTRACT

Purpose: Mobile health or mHealth research has been growing exponentially in recent years. However, the research on mHealth has been ad-hoc and selective without a clear definition of the mHealth domain. Without a roadmap for research we may not realize the full potential of mHealth. In this paper, we present an ontological framework to define the mHealth domain and illuminate a roadmap.
Methods: We present an ontology of mHealth. The ontology is developed by systematically deconstructing the domain into its primary dimensions and elements. We map the extent research on mHealth in 2014 onto the ontology and highlight the bright, light, and blind/blank spots which represent the emphasis of mHealth research.
Findings: The emphases of mHealth research in 2014 are very uneven. There are a few bright spots and many light spots. The research predominantly focuses on individuals' use of mobile devices and applications to capture or obtain health-related data mostly to improve quality of care through mobile intervention.
Conclusions: We argue that the emphases can be balanced in the roadmap for mHealth research. The ontological mapping plays an integral role in developing and maintaining the roadmap which can be updated periodically to continuously assess and guide mHealth research.

1. Introduction

Mobility is central to the notion of participatory healthcare. It provides freedom from temporal and spatial constraints to both providers and recipients of healthcare, and thus facilitates their participation in healthcare. Not surprisingly, the domain of mobile health, or mHealth as it is commonly denoted, has garnered much attention in recent years as its application has come to permeate the healthcare industry. The concept of mobility has evolved from the physical transportation of healthcare staff and equipment to simply transporting information using modern technologies [1]; a novel paradigm that begins in telemedicine and telehealth [2], giving rise to the concept of eHealth with mHealth as its subset [3]. The smartphones and associated technologies represent the next stage of the evolution in 'transporting information to transform healthcare' [4], and consequently mobility of and participation in healthcare.

There has been an explosion of research on mHealth in the last few years. There are altogether 808 mHealth articles with abstracts indexed in PubMed between 2013 and January 2015 when the data was collected, of which 364 (45%) are from 2014. Similarly, the number of mHealth articles indexed in Scopus has seen an exponential increase since 2010 [1]. The numbers are likely to grow unabated.

Research on mHealth has been selective, largely focusing on the mobile applications or apps, based on several reviews of the domain. "Most studies narrowly focused on text messaging systems for patient behavior change, and few studies examined the health systems strengthening aspects of mHealth." [5] This statement aptly reflects the narrow focus of the mainstream mHealth research. The domain of mHealth however transcends mobile applications or text messaging. It stands at the crossroads of information and communication technologies (ICT) and patient- and outcome-oriented healthcare. Regardless, the landscape of mHealth research is scattered with narrowly-focused research niches. Most studies emphasize behavior change, intervention, or self-monitoring for adherence to treatment or medication [6–12] while others focus on adoption or specific characteristics of mobile applications [13–20]. A few others examine the use of mobile

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technologies in prevention, diagnosis, treatment, patient care, and education in general [21–24].

Amidst this rapid explosion of interest, the definition of the mHealth domain remains unclear. Researchers have focused selectively on different parts of the whole, neglecting the 'big picture'. This selectivity results in fragmentation of the research agenda; the sum of the parts simply falls short of making the whole. There is a need to articulate and make the combinatorial complexity of mHealth visible to facilitate effective research on mHealth systems [25]. "The current confusion in the nomenclature and classification hinder telemedicine research ... it frustrates our efforts to reach a reasonable understanding of what we already know and what we need to know. Equally important, it impedes progress toward development and implementation of a research agenda geared toward reaching answers to questions regarding the true benefits and costs of telemedicine." [26,p. 492] With these concerns in mind, we use an ontology to frame and represent the complexity of mHealth. The ontology can be used both prospectively to construct a roadmap to guide research and retrospectively to map and assess present research in the domain. The ontology and the mapping can be updated periodically to refresh the roadmap.

We will first review some key definitions of mHealth and then logically deconstruct the concept using an ontology. We will then describe how the ontology can be used to define the domain of mHealth, and how it can be extended, reduced, refined, and coarsened to adapt to the evolving technology and environment for healthcare. Last, we will delineate how the ontology can be used to map the state-of-the-research and the state-of-the-practice in mHealth, discover the gaps in research and between research and practice, and formulate a strategy to bridge those gaps and generate synergy—all with the goal of making the whole greater than the sum of its parts.

1.1. Definitions of mHealth

The term mHealth and its variant m-Health date back nearly twenty years, a period that has seen their definition shift within both the landscape of health technologies and the discipline to which they were applied. The definitions suggest the dimensions and elements of the mHealth domain but do not comprehensively denote the domain. We will present and discuss these definitions, and in the next section draw upon them to construct an ontology of mHealth.

Istepanian, Jovanov and Zhang [27] define mHealth [they spell it m-Health] as "mobile computing, medical sensor, and communications technologies for healthcare." As the title of their article suggests, they envision it leading to "...seamless mobility and global wireless health-care connectivity." In a more recent article they suggest the "...*evolution of m-health towards targeted personalized medical systems with adaptable functionalities and compatibility with the future 4G networks*." [28,italics in the original] Their definition focuses on the hardware and networks driving the transition, and the potential impact on healthcare in general due to enhanced connectivity. It is a technology-based definition.

Akter, D'Ambra and Ray [29] define "mHealth... as the use of mobile communications such as PDAs and mobile phones for health services and information. Researchers have recently extended the definition of mHealth by focusing on any wireless technologies (e.g., Bluetooth, GSM, GPRS/3G, Wi-Fi, WiMAX) to transmit various health-related data content and services through mobile devices, including mobile phones, smartphones, PDAs, laptops and Tablet PCs." Further, they suggest that the ubiquity of mobile phones "is a central element in the promise of the mobile platform for healthcare." [29] Like the previous, this definition is singularly technology-based.

The World Health Organization affirms the absence of a standardized definition of mHealth [30]. It goes on to use the definition of mHealth as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants (PDAs), and other wireless devices... [It] involves the use and capitalization on a mobile phone's core utility of voice and short messaging service (SMS) as well as more complex functionalities and applications including general packet radio service (GPRS), third and fourth generation mobile telecommunications (3G and 4G systems), global positioning system (GPS), and Bluetooth technology." [30] Speciale and Freytsis [31] use the same definition in their call to action for midwives. This definition too is primarily anchored on technology with reference to both medical and public health practice instead of healthcare in general; the two healthcare areas have different stakeholders and information management needs.

Nacinovich [3] defines mHealth as a subsection of eHealth. It is "the use of mobile communications for health information and services... to improve health outcomes." This definition does not focus on the technology but on health information, services, and the outcomes the technology may enable. It complements the earlier definitions.

In contrast to the above definitions, Bashshur, Shannon, Krupinski and Grigsby [26] hierarchically deconstruct mHealth (they refer to it as m-Health) as a component of the ICT (Information and Communication Technology) health domain. Within this domain, they portray the progression from Telemedicine to Telehealth to eHealth (or e-Health) to mHealth. They propose four components of the mHealth domain: clinical support, health worker support, remote data collection, and helpline [26]. They further suggest functionality, applications, and technology as the three basic dimensions of any telehealth (including mHealth) system. Each dimension has many components.

It is understandable that many of the definitions are driven by the 'm' for mobile technology. The technology is the catalyst. Yet the technology must be embedded in a mobile system for healthcare to be effective. These definitions do not embody a systemic view of the information system in which the technology is embedded, nor do they explicitly include the participation of stakeholders and the final outcomes of the healthcare system for which it is intended. They do not capture the combinatorial complexity of the domain. The definition proposed by Bashshur, Shannon, Krupinski and Grigsby [26] comes closest to doing so, but it too suffers from the type of selectivity bias that risks skewing the design of the system and undermining its effectiveness. Using definitions such as those illustrated, designers and users may fail to see the 'big picture'—they may develop excellent technological solutions but whose effect on healthcare is unpredictable. In the next section, we logically deconstruct mHealth and define its domain using an ontological framework.

1.2. Ontology of mHealth

It is difficult to effectively present the full complexity of mHealth using a linear natural English narrative. Such a narrative would be too voluminous and increase the risk of selectivity in its research and application. On the other hand, a structured natural English representation using an ontology can be parsimonious and effective in capturing the complexity of mHealth, while making it visible and comprehensible. The ontology is a combinatorial, visual, natural English representation, which can also be translated into other languages. In this section, we present an ontology of mHealth.

An ontology represents the conceptualization of a domain [32]; it organizes the terminologies and taxonomies of the domain. It is an "explicit specification of a conceptualization," [33,p. 908] and can be used to systematize the description of a complex system