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Mobile and wireless technologies in health behavior and the potential for intensively adaptive interventions

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Recent advances in mobile and wireless technologies have made real-time assessments of health behaviors and their influences possible with minimal respondent burden. These tech-enabled real-time assessments provide the basis for intensively adaptive interventions (IAIs). Evidence of such studies that adjust interventions based on real-time inputs is beginning to emerge. Although IAIs are promising, the development of intensively adaptive algorithms generate new research questions, and the intensive longitudinal data produced by IAIs require new methodologies and analytic approaches. Research considerations and future directions for IAIs in health behavior research are provided.

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Introduction

Assessments of real-time and real-world health behaviors and their influences are rooted in various research traditions including ambulatory monitoring, diary studies, and prompted self-reports [1]. The repeated sampling of behaviors and experiences in real-time, Ecological Momentary Assessment (EMA), has developed into a mature methodology that provides important findings not possible from retrospective reports [2•]. Recent advances in mobile/wireless technologies and the integration of these data with data from other digital sources have enabled unprecedented capabilities to intensively assess health behaviors 'in the wild.' Ninety percent of U.S. adults own a cell phone, and nearly two-thirds own a smartphone (Pew Research Center; URL: http://www.pewinternet.org/fact-sheets/mobile-technology-fact-sheet), providing a ubiquitous personal device to deliver EMA as well as to sense location, activity, and other relevant health behavior variables.

Passive wireless sensor capabilities also are developing rapidly, both in the scientific and commercial sectors. Accelerometry for physical activity assessment has been the most established sensor technology for research purposes [3], but sensors are now available to assess environmental exposure, location, physical activity, sleep, social interactions, and images of the person and environment [4]. Wireless sensors for physiological parameters such as blood pressure, heart rate, and respiration rate are of sufficiently high quality for approval by the U.S. Food and Drug Administration for use in hospital settings [5]. Recent advances in nanosensing and biosensors have led to the development of implantable biosensors [6] and nanosensors nested in a gum base to monitor biological activity [7].

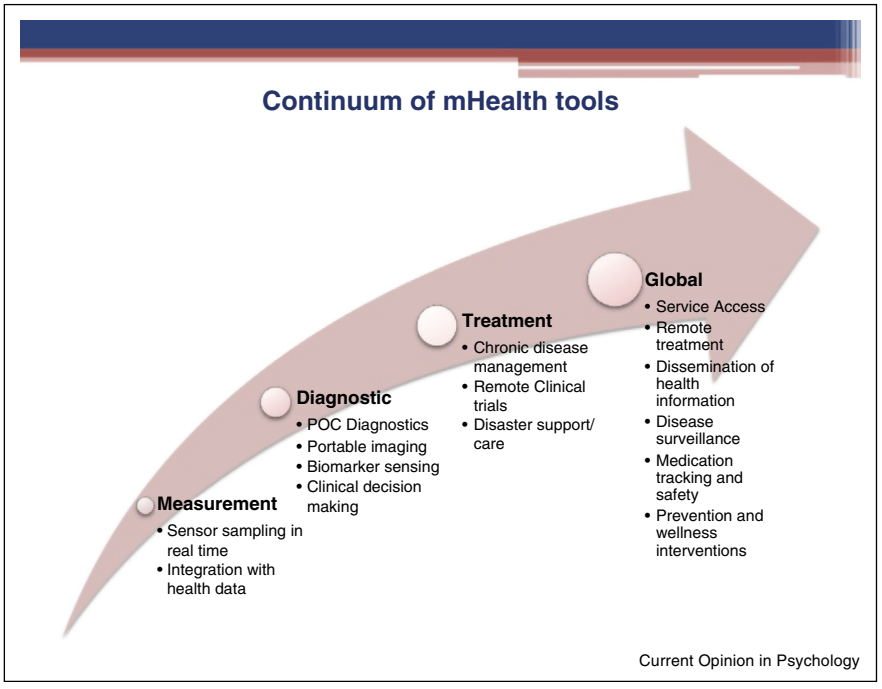
A recent development is the integration of several physiological and behavioral sensors into a 'smartwatch' that it is conveniently wearable for long durations [8]. Although the quality of measurement remains unknown, these smartwatches include activity monitoring, heart rate, and blood pressure with future plans to add glucose, blood pressure and other physiological parameters. The quality of these commercial measures remains unclear, and validation with standardized measures needs to be actively pursued by the research community.

These mobile and wireless health (mHealth) technologies have developed at an exponential pace in recent years, but the integration and translation of these cutting-edge technologies into rigorously evaluated health research and healthcare tools have not kept pace. Remarkable technological advances have been made in the last decade, and with sufficient research and evaluation, these technologies provide the potential to advance research, prevent disease, enhance diagnostics, improve treatment, reduce health disparities, increase access to health services, and lower healthcare costs in ways previously unimaginable (see Figure 1).

Leveraging real-time assessment for intensively adaptive interventions

The rapidly expanding repertoire of real-time inputs relevant to health behaviors provides the potential for intensively adaptive interventions (IAIs). Earlier technological advances such as Internet-delivered interventions were critical to the development and implementation of

Figure 1



Continuum of mHealth Tools.

tailored interventions in which baseline information is used to match the intervention to the individual [9]. Adaptive interventions adjust the intervention not only at baseline but also at various points throughout the intervention process [10•]. The Sequential Multiple-Assignment Randomized Trial (SMART) compares the decision points of adaptive interventions in which the next course of intervention is based on the prior intervention response [11].

These adaptive interventions typically make intervention adjustments after a few weeks or months of intervention. In contrast, IAIs make these adjustments every few days, hours, minutes, or even seconds utilizing real-time inputs. An IAI adjusts the timing and content of the intervention at any time point based on the response to previous intervention outputs as well as intrapersonal state and social/environmental context. IAIs have been made possible by the rapid proliferation of mobile and wireless technologies, which allow real-time and intensive assessment as well as intervention delivery throughout the day.

IAIs have also been described as Just-in-Time Adaptive Interventions (JITAIs) and Ecological Momentary Interventions (EMIs). The term 'JITAI' has computer science origins and denotes that these IAIs are not delivered in 'real-time', that is, immediately in response to the input, but instead 'just-in-time' after a meaningful series of inputs that can be obtained to select an intervention with appropriate content for the appropriate time and place [12]. The term EMI derives from EMA and denotes that mobile devices can be used not only to prospectively obtain self-reports throughout the day, but also to deliver interventions based on these self-reports and other mobile inputs [13•,14]. The review of 27 EMIs [13•], however, included very few interventions that were intensively adaptive [13•], a finding consistent with our own review of mobile interventions [15•]. Therefore, although we believe that JITAIs and EMIs have similar connotations, we have used IAI to clearly describe an intervention that adapts rapidly (within a day or two at most, but typically within hours) in response to real-time inputs from sensors and EMAs. Using the first author's prior work for illustration, a text message smoking cessation intervention included in the Heron and Smyth EMI review [13•] that adjusts text content and frequency based on time of day and quit date [16] would not be considered an IAI because the adjustments were not based on real-time inputs. In contrast, a special purpose device for scheduled gradual reduction of smoking that adjusted the interval to the next prompted cigarette based on when the user smoked in response to the previous prompt [17] would be considered an IAI despite its dated technology and algorithms.

Studies of IAIs for health behavior interventions are beginning to appear in the literature. In a small study, Adams and colleagues evaluated an adaptive intervention that generated personalized daily physical activity (step) goals and micro-incentives adjusted based on previous