Mobile Health Technologies

Hemant K. Bhargava
Graduate School of Management, University of California, Davis, Davis, California 95616
hemantb@ucdavis.edu

Julia Tanghetti
Graduate School of Management, University of California, Davis, Davis, California 95616
jctanghetti@ucdavis.edu

Abstract

Mobile health solutions are expanding rapidly and have become a part of the health care landscape. Over a hundred thousand mobile apps exist today, and create value in very diverse ways. This paper proposed a framework for classifying mHealth solutions on three dimensions, type of technology (form factor), level of institutional integration, and function. It examines the underlying process by which different types of mHealth applications create value, and maps the classification dimensions to potential ways in which these solutions can impact patient health, costs, and other metrics. The optimal choice and design of mHealth technology will depend on patient population characteristics or the settings in which these technologies are deployed. We apply this classification by reviewing a small number of mHealth applications which have been described in the literature. In many cases, the potential impact of such technologies may not be easy to identify, to measure, or to attribute it to the technology. Moreover, while many solutions aim to make patients better informed, this may not necessarily lead to better patient health, because there is evidence in other domains that, when given more information and control, non-experts develop over-confidence, make poorer decisions, and achieve worse outcomes.

Today's computing devices are extremely powerful, small, lightweight and ubiquitous. One such device is the modern smartphone, which carries more processing power than was available to NASA when it landed the first man on the moon in 1960. These tiny devices also have incredible capacity to communicate data, documents, images and video across the world. As general purpose computers, they have unlimited capability for information processing, due to which over a billion applications are available on iTunes and Google Play, the dominant repositories of smartphone apps. These applications range from what some might consider frivolous (e.g., the app "Yo" which lets users message each other with just the word "Yo"), to ones used to signal status (e.g., the app "I Am Rich" which costs $999 and does nothing), to others that hope to save the world (e.g., detecting the spread of life-threatening diseases). Smartphones have also witnessed an unprecedented penetration rate, reaching over a billion people in just a few years.

Not surprisingly, many entrepreneurs and researchers are excited about the possibility of harnessing the phenomenal power and reach of these mobile technologies. One area of particular interest is also one of the biggest sectors of a modern economy, health care. Mobile health (or, mHealth) technologies are expanding rapidly. A recent article notes that “over 100,000 health apps are available in the iTunes and Google Play stores, according to Research2Guidance, a mobile market research firm” (Krisch 2015). These apps range from motivating users into a regular fitness regimen to tracking health metrics and even medical interpretation and advice. Concurrently, several leading healthcare organizations have begun making major investments in developing mobile apps and integrating them into the healthcare process.

A recent study of the U.S. wireless industry by Roger Entner found that mobile devices improve worker productivity in four critical ways: reducing unproductive travel time, improving logistics, enabling faster decision-making, and empower small businesses and improving communications. Entner projects productivity gains from wireless in the medical industry to reach $305 billion over the next 10 years (Entner 2012). The gains from mHealth technology have the potential to extend beyond the patient to the entire healthcare system.

Mobile health technologies hold the potential to fundamentally change and improve healthcare experience and outcomes. But mHealth technologies are extremely diverse in the impact they can potentially have. It can be hard for both developers and adopters to understand the potential of a specific technology, which also makes it difficult for developers to build the solution in a way that realizes its true potential. As Damien Bennett recently noted in the BMJ, just distinguishing between the different types of health apps is critical to understanding how these technologies may affect individuals. (Bennett 2015) This article aims to shed some light on this subject by classifying different categories of mobile health apps, and discussing the potential impacts of each of these categories by means of illustrative examples. We describe a framework to classify apps based on the type of technology deployed, the level of institutional integration, and the purpose of the technological intervention. We then examine a set case examples to illustrate the application of the framework, employ the framework to analyze the nature of impact, and discuss how aspects of the framework can facilitate or limit different types of impact. We also comment on additional factors needed to ensure that the intended impact is actually achieved, measurable and demonstrable.

Types of Technology Deployed in mHealth Interventions

One dimension useful in classifying mHealth solutions is the form factor (or, simply, form) of the technology. The common form factors are “app”, “sensor” and “device”. As explained below, these form factors differ on critical capabilities such as the ability to capture data, the ability to process data, and the ability to communicate the data.

An “app” is a software application, usually running on a smartphone or other handheld device that has an operating system and network connection. Therefore it is capable of receiving and communicating data, some level of resident computing power, plus the ability to leverage the power of networked computers on a remote cloud. Because of these features, a mHealth app could potentially be weaved into a bigger and broader solution that could encompass physicians, hospitals, pharmacies and insurance companies. For instance, an app might employ SMS (short message service) to promote treatment or medication adherence. An app does not, however, have the capability to capture and collect data on its own, such as a patient’s blood pressure, level of pain, dosage of medication consumed etc. It requires human or other intervention to capture data and to enter it into the solution environment. Many mHealth applications currently on the market are stand-alone apps. Despite their ability to leverage the power of general-purpose computing and communication, their potential impact remains constrained by the limitations of self-reporting: possibility of errors in data capture and transcription, inability to automatically collect data based on certain triggers, and failure to collect and report the data at required intervals.

A “sensor” is usually physical hardware that is capable of automatic data capture. The key advantage of sensor-based solutions is that they take the burden off patients for self-reporting their own data. A sensor is usually embedded into a communication device so that the collected data can immediately be transmitted to another piece of the overall solution. Sensors may also have integrated data storage capability, so that repeated observations of the data may be stored, and then transmitted in batch mode. With some sensor-based mHealth solutions, the physical hardware may be endowed with limited computing and communication capabilities, to extend the solution into a special-purpose “appliance”. For instance, a Fitbit may link to and share data with other Fitbits in the patient’s social network.

Finally, mHealth devices may combine app and sensor capabilities into a general-purpose computing environment. The most direct way to achieve this is to augment a general-purpose computing device with sensors that feed information to the device. For example, the iGBStar solution from Sanofi Aventis is a blood glucose monitoring device for diabetes patients that connects directly into Apple phones. Blood glucose readings from the device are uploaded to a diabetes manager app that allows patients to track their condition. As biosensors become increasingly more sophisticated and discreet, researchers are also evaluating their use in conjunction with mobile applications given the ultimate aspiration for passive monitoring solutions. MHealth solutions that incorporate devices for measuring or sensors for passive monitoring take the burden off patients for self-reporting their own data. Additionally, when deployed successfully, devices and sensors give patients the ability to record and transmit their biometric data into a user interface providing an actionable and informative picture of their health that can be shared with physicians, caregivers, family members, or their social networks (Steinhubl, Muse, and Topol 2015).

Level of Institutional Integration

The development and deployment of patient-centric mHealth solutions create numerous possibilities for the participation of other institutional players involved in health care provision and regulation.

Development	Deployment
● Stand-alone ● Expert-certified ● FDA Approved ● Approved by insurance provider	● Stand-alone ● Requires physician prescription ● Provides data to caregiver ● Caregiver logic and rules embedded into system functioning

Pharmaceutical companies, physicians, hospitals and medical researchers can potentially be involved in development and testing of a new solution. Such testing can produce a valued seal of approval, which can be useful in marketing the product. For instance, if a solution seeks to measure a patient’s cardiac activity and create alerts based on certain triggers, then suitable medical testing and certification can convince users that the product functions as certified. The developer can also try to secure FDA approval for the product, which provides a further certification of safety, or at least that "benefits of the product outweigh the risks for the intended use".

Similarly, multiple institutional players can be involved in deployment and use of the solution. For instance, mHealth solutions may communicate patient data to the patient's care provider either in real-time or batch mode, or may make it available when the patient visits the care provider. Physician participation may also be integrated into the solution more deeply, either by embedding physician-provided rules and logic into the system, or by creating mechanisms for real-time input and advice from physicians. For instance, such rules and logic might be used to compute medication dosage for the patient, or to personalize a self-managed physical therapy routine.

While over 100,000 health apps are currently available on iTunes and Google Play, a vast majority of these are "stand-alone" solutions that are used by the patient but have no institutional connectivity either in the development process or in use. Only approximately 100 apps are FDA approved (Foreman 2013). This might be explained by the FDA's risk-based approach to regulating mobile health apps, which focuses on apps that meet the criterion for medical devices. Due to this, only apps that meet the regulatory criteria for a medical device and "are intended to be used as an accessory to a regulated medical device, or transform a mobile platform into a regulated medical device" are potentially subject to FDA approval ("Mobile Medical Applications" 2014). While the FDA approval process imposes costs of both time and money on mHealth app developers, gaining approval may impart a legitimacy upon these apps that could be useful in increasing adoption in both healthcare providers and patients. Furthermore, as the healthcare system begins to answer the question of whether mHealth technology use is reimbursable, having FDA approval for mHealth apps may become critical. Given institutional knowledge of the FDA approval process, both medical device manufacturers and pharma companies may be advantaged due to their experience in this area. However, many mHealth applications do not fall under FDA purview and it may be possible for these technologies to create value without meeting the regulatory criteria for a medical device. In general, a greater degree of institutional integration creates greater barriers to entry and deployment, but also enhances the potential impact of a mHealth solution.

Functions of mHealth Technologies

The form factor of mHealth technologies, app, device and sensor, works in service of the underlying functionality of these technologies. While mHealth technologies may have a variety of stated aims, such as improving medication adherence or helping patients gain control of chronic conditions, these aims do not capture the underlying function by which these technologies enable behavior changes. In examining how mHealth technologies enable behavior change, there are several broad functions that may drive these solutions regardless of the problem they are trying to solve or condition they treat. Viewed broadly, mHealth technologies may have any of the following functions or they may combine them to achieve the desired result.

Functions of mHealth Technologies
• Inform • Advise • Communicate • Measure • Monitor • Motivate

Examining the various functions of mHealth technologies helps illuminate the potential impact of these technologies. An app may inform users by educating them on their disease state or medications they take. These technologies also may advise patients if their symptoms or readings necessitate the need for a visit to the doctor or a change in their medication. The mHealth technology can also enable communication with a patient's healthcare team. Through either self-reported outcomes or data captured through devices or sensors, patients can measure their disease biometrics. Through integrating these same patient-reported outcomes or results of passive data collection mHealth technologies may provide data visualization allowing both patients and physicians can monitor a patient's condition and track progress over time. Finally, many mHealth technologies fundamentally seek to motivate patients to make better health decisions. This may come in the form of motivational messages that reach patients at the right time, such as when they need to take their medication.

While mHealth technologies can combine these functions to enable better health outcomes, they also may employ these purposes to varying degree. For example, looking at the function of communication, an app may provide for communication with a patient's care team through the ability to email a patient's physician the data from the app. Alternatively, an app may also automatically push data to the physician or automatically integrate it into the patient's EMR. Thus along this dimension of communication, mHealth solutions may vary in the degree to which this function is implemented. This classification of function and degree of function is important in steering the discussion of mHealth technologies towards the potential impact these solutions can have on the health care system.

Case Study Examples

Ovia Pregnancy Tracker and Baby Calendar

Ovia, the pregnancy tracking app from Ovuline, allows women to track the progress of their pregnancy and provides personalized feedback to users from conception to birth. Ovia has over 1 million active users, which speaks to the fact that many women have found the app to be of some value during their pregnancies (Pai 2015). As of May 2015, Ovia was number eight in the App Store for free medical apps. Through both user reported data and data which can be uploaded from fitness and sleep trackers, the app allows users to measure their progress and monitor changes over time through analyzing users' data and visually charting it, allowing users to see their data mirrored back to them. Based on the stage of pregnancy or symptoms a woman is experiencing and reporting, the app curates personalized articles to educate and inform. Ovia allows women to communicate their progress, as the data from the app can be exported via text, email, or uploaded to social media. Presumably women could share this information with their physician as well, however, the app does not allow users to send this data to their physicians using a physician's portal or using EMR integration, so this communication function is limited. The app suggests goals for weight based on pre-pregnancy BMI (body mass index), sleep, nutrition and exercise, helping and motivating expectant mothers towards healthy behaviors. The app also provides an advisory function if a user enters symptoms that may indicate a health risk, the app also alerts them to contact their physician.

While the Ovia pregnancy app combines many of the functions of mHealth applications, the app is not well integrated into the formal health care system. The app does not enable efficient contact with users' health care providers, but it seems to have the potential to succeed in making pregnant women more informed and empowered patients. Recently Ovuline announced the launch of Ovia Benefits, which allows women to choose their health insurer in the app and then receive health plan specific information (Pai 2015). While over 250 health plans have signed up to participate in the program, their levels of partnership with Ovuline vary. Blue Cross Blue Shield of Massachusetts launched a pilot program with Ovuline in February of 2015 which allows users of the app on that health plan to receive location specific information and information about health care services the plan offers, such as gestational diabetes screening (Bartlett 2015). This move reflects the broader push in the health care system towards empowering and engaging patients. Additionally, it suggests that without integration into the formal health care system, these apps reach a limit in the value they can provide.

Mango Health

Mango Health provides an app for users to manage their medications. The app utilizes both gamification and rewards to promote medication adherence. Users enter their medication and dosing schedule, then the app provides reminders to users to take their medications. The app can also educate users about drug interactions and side effects. Users earn points every time they report they have taken their medication correctly and these points accrue, giving users the chance of winning rewards like gift cards. With the data from the app, Mango Health reports that users show an increased adherence to anti-hypertensives to 89%, versus 59% average for the general population, adherence to diabetes medication at 85%, versus 51% average, and adherence to statins to 84%, versus 52% average (Comstock 2014). However, it is not clear if this data is self-reported from patients. As such, its accuracy is questionable.

While Mango Health started as a consumer-focused technology, the company is seeking greater integration with the health care system. Mango Health's CEO Jason Oberfest has noted that the company is partnering with "one of the top three integrated care delivery systems in the country, one of the top three pharmacy benefit managers, and one of the top five largest US health plans" (Comstock 2014). Mango Health's statistics show that users average 17.1 sessions per week and 77% of active users open the app every day (Cutler 2015). While these are impressive statistics for any type of mobile application, Mango Health's move towards a greater health system integration may be indicative of the limits in impact this app faced as a primarily direct-to-consumer product. While an app encouraging medication adherence is valuable, without connecting this potential for behavior change to the healthcare ecosystem, its impact may be blunted.

Ginger.io

Some mHealth technologies are starting to embrace the idea that the way patients interact with all types of technology in their lives, including smartphones and social media, may be indicative of the health of the individual. Dr. Sachin Jain of CareMore recently proposed the idea of a "digital phenotype," which holds that a patient's digital footprint contains information that is clinically valuable to physicians (Jain et al. 2015). Ginger.io's platform of a mobile application, behavioral analytics engine and physician dashboard builds upon this insight in their solutions for depression and behavioral health. Combining short daily surveys with passive data collection from smartphones, Ginger.io can detect warning signals in a patient's behavior that might be problems and alert the patient's care team, who can then intervene. For example, if the application detects that a patient hasn't left their house in three days or is unresponsive to texts and calls from friends, this may presage a slip into a depressive episode. This can help physicians detect symptomatic episodes in between regularly scheduled visits and allow them to help their patients at the right time. Ginger.io also purports to help drive down healthcare costs for these conditions by a more efficient use of resources, reduced admissions into high-cost care settings such as the emergency room, and extended health care capacity. While a small pilot study of the platform conducted in conjunction with Verizon and The Centerstone Research Institute showed a decrease in hospitalizations and readmissions in the 10 patient group of Medicare "super users" in the study, more research is required to determine if these results can be replicated on a larger scale ("Solving Healthcare's Superutilizer Challenge" 2015).

Ginger.io mobile and web platform creates value on all levels of the proposed framework. The app provides convenience to patients given that much of their data is captured passively. The behavioral analytics engine gives patients, physicians and caregivers the ability to understand how this data is reflective of the health of the individual. Finally, this platform also enables the ability to reach patients when they need help most, thus meeting requirements for the high-value impacts that are possible with mHealth technologies.

AliveCor

The AliveECG app and complimentary Heart Monitor device enable patients to capture their ECG (electrocardiogram) and heart rate. The FDA approved app alerts patients if their ECG is normal and it can also detect possible atrial fibrillation. Patients can either send this data to their physician for review or patient in the US can also pay a fee to have their ECG read by either a cardiologist or cardiac technician. The technology could be used for various patient types. Patients who may suspect a heart arrhythmia but are asymptomatic during doctor's visits could use this device when they experience they symptoms, thus helping physicians accurately diagnose the condition. Alternatively, this device could be used for patients that have been diagnosed with atrial fibrillation to track the efficacy of other care interventions such as medication. By monitoring patients over time, the device could help providers determine if their prescribed therapy is working. While no clinical studies have been published tying this device to health outcomes, a feasibility study for the device, monitoring patients after an atrial fibrillation ablation procedure, showed that patients preferred this device to a traditional transtelephonic monitor (TTM) and found it easy to use (Tarakji et al. 2015).

This device and app provides patients with an easy solution to measure their ECG's and heart rate and monitor their condition over time. It also gives healthcare providers the ability to monitor their patients' progress in between regular office visits through either emailed reports, a physician dashboard or integration with one EMR provider. However, users of the app must have the ability to properly understand and react to the information captured and reported by the device. For example, AliveCor has had to emphasize in the past that this device is not intended to diagnose heart attacks (Dolan 2014). Additionally, if a patient detects a possible atrial fibrillation with the device and is not properly educated on what response to take, this may result in an escalation such as an unnecessary office visit or ER trip. This problem raises the question of how much data is actually beneficial to patients. Additionally, without educational content and clear and understandable data visualization, these type of apps may not be effective tools to help patients monitor their condition.

BlueStar by WellDoc

The BlueStar app by WellDoc is the first FDA approved mHealth application available only by prescription, which fully integrates this solution into the traditional health care system and thus provides a mechanism for health plan reimbursement. The BlueStar app and accompanying physician portal have shown success in treating patient with Type 2 diabetes. In a cluster randomized trial involving 26 practices and 163 patients in Maryland, patients using the app had a 1.9% decrease in glycated hemoglobin levels over 1 year, compared with a 0.7% decline in the standard of care group (Quinn et al. 2011). The app provides patients with a way to keep a digital journal of their condition through self-reported data tracking glucose readings, medications, food and exercise. Based on the information patients enter, BlueStar can provide motivational messages, educational tips, or suggest action. Because the app recommends treatments for the disease, it falls under the purview of FDA regulations. For example, if a patient using the app enters a low blood glucose reading, the app might provide specific instructions to eat a certain amount of fast-acting carbohydrates to help regulate levels. Alternatively, the app may alert the patient when they need to take a specified amount of insulin. Though the physician portal, a patient's care team can track how they are managing their condition between visits.

While this app combines many functions of mHealth technologies, in that it provides a mechanism for communication, motivation, advice, measuring and monitoring, the self-reported nature of the patient data provided poses problems for both patients and healthcare providers. For patients, entering all the data on every blood glucose reading, medication taken or food eaten certainly seems to present a rather onerous burden. Additionally, if a patient is only entering measures for blood glucose readings but fails to enter their medication or diet choices, the question of whether the app can provide appropriate advice is unclear. Similarly, if the patient is not entering all the relevant data, the clinical value to health care providers is unclear.

Mayo Cardiac Surgery Patient Recovery Study with Fitbits

While the case studies already discussed involved technology deployed primarily for patient use, mHealth technologies may also be utilized primarily for the use of physicians and patient care teams. The Mayo Clinic recently published a study that examined the length of stay in hospital for post-operative cardiac surgery patients and incorporated Fitbits to track patients' levels of activity in recovery (Cook et al. 2013). This study followed elderly patients (age 50 and above) and patients were equipped with a Fitbit attached to their ankle. The data from the Fitbits was transmitted to a physician dashboard. The study showed a significant relationship between the number of steps taken in the early days of recovery and the length of stay in hospital and dismissal disposition.

While much of the literature on mHealth touts the potential for patient behavior change, this study is interesting because it shows a practical use for these technologies in a physician-focused way. The study notes that patient mobility data is generally captured twice or three times daily by the nursing staff, if at all, but these notes are not part of the workflow of the surgical team. The Fitbit sensors enabled the continuous capture of objective data that is easily accessible to the care team and can facilitate in the decision of when to discharge patients. While the study had a narrow focus of measuring steps and monitoring patients, the use of such technologies has the potential to impact both patient outcomes and hospital resource utilization (Cook et al. 2013). Additionally, while this study only followed patients during their stay in hospital, this technology could also be utilized to follow patient recovery once they have left hospital and returned home or transferred to a skilled nursing facility. Mayo is also studying patient-focused apps post-surgery. The integration of a patient and physician platform would seem to hold even greater potential to affect patients' post-surgical outcomes and potentially reduce length of stay and hospital readmissions.

Classification of Examples

mHealth Technology	Type of Technology	Level of Institutional Integration	Function
Ovia Pregnancy Tracker	App	Low	Inform Advise Measure Monitor Motivate
Mango Health	App	Low	Inform Measure Motivate
Ginger.io	App and Sensor	High	Advise Communicate Measure Monitor
AliveCor	App and Device	Medium	Communicate Measure Monitor
BlueStar by WellDoc	App	High	Inform Advise Communicate Measure Monitor Motivate
Mayo Clinic Fitbit Recovery Study	Sensor	Medium	Measure Monitor

How do Mobile Health Technologies Deliver Value?

Motivated by the underlying question of “how do mHealth solutions create value”, the preceding discussion has offered a framework for classifying mHealth solutions along 3 dimensions, “type of technology”, “level of institutional integration” and “function”. We described several real-world examples of mHealth solutions to illuminate how the position of a solution along these three dimensions can create possibilities and impose limitations on the potential value created by the solution. The case studies also illustrate that mHealth solutions can provide several levels of value.

- Behavioral change
- Medication adherence
- Change in health system utilization
- Quicker diagnosis
- Patient health outcome
- Patient satisfaction ("feel good")

Some mHealth solutions may induce a positive behavioral change in the patient (e.g., better fitness regime or better diet, or more timely visits to a medical clinic). Commonly used techniques are motivational tools, better information and data-tracking, gamification, and social competition. In a similar way, mHealth solutions, such as Mango Health or BlueStar, can also improve medication adherence and more generally, adherence to a treatment protocol. Further, mHealth solutions, such as Ginger.io, might cause a change in the degree to which patients employ the health system, such as a decline in emergency visits or utilization of expensive procedures.

The collection of mobile health technologies available today is extremely diverse, hence there is also huge diversity in the nature of their impact, what sort of value they create, and who they create value for. Many of these technologies have the power of general-purpose computers, even though they may look nothing like a standard computer. Examining these mHealth technologies through a framework that technologists have often used to understand the value of computer-based technologies, we see that such systems are developed for purposes of Convenience, Computation, and Chestnuts (Kimbrough et al., 1990).

The first purpose, Convenience, represents the most rudimentary use of computer-based technology. Computers can greatly simplify, or significantly lower the cost of, data-related activities, including data capture, measurement, and storage. Hence they can vastly increase the frequency of these activities. For instance, many mHealth apps and devices seek to measure and maintain data about some health-related metrics such as glucose level, blood pressure, or temperature. They may be viewed as electronic versions of notebooks that a patient may otherwise keep, with periodic notations about these metrics. However compared with traditional notebooks and data capture, the app or device delivers such extreme convenience that it can make these activities incredibly granular. The vast majority of such apps are patient-centric, and deployed by private developers who transact directly with the patient. Hence their benefit tends to remain limited to giving patients better information, or motivating and inspiring them to make behavioral changes in response to observed data.

The second purpose, Computation, begins to truly leverage the power of these computer-like technologies. These applications create value through computation, which may cover mathematical processing, data visualization, storage and retrieval, and communication of the data. For instance, an app that captures a patient's blood pressure may communicate its readings to the patient's health care provider, whereupon the chart could be displayed to an attending physician on the patient's next visit. Such solutions usually require integration into the patient's health care system. It creates the potential for higher value because the information now becomes available to those who can best interpret and leverage it. Such applications also have the potential to benefit multiple stakeholders besides just the patient.

The third purpose, Chestnuts, reflects truly high-value mHealth solutions which leverage the power of today's technologies to deliver transformational results. These solutions not only deliver information to the right person in the right format, but do so at the right time. This is especially relevant for time-critical medical events. For instance, consider a device like AliveCor that monitors cardio-related metrics and, upon sensing a potential anomaly, instantly conveys relevant data (e.g., an ECG) to multiple cardiologists (who may be located anywhere and have signaled availability to immediately review the data). Within minutes the app receives opinions from multiple experts, then makes a determination whether the patient needs immediate and expert care, picks a health care facility and physician for the patient, and communicates all relevant data to the physician. While this device does not currently allow for such a level of functionality, it is certainly possible. In such time-critical health care events, this ability to make a timely determination and arrange for care can be life-saving. It would simply not be possible without the kind of mobile technologies that are available today.

Even when a solution has some "intended" purpose, there are several notes of caution regarding the evaluation of this purpose. The solution may be unable to realize the intended purpose (e.g., because of unfavorable conditions in deployment, or incorrect usage by patient), because there might not be clear and quantifiable metrics to determine the extent to which the purpose was realized, and moreover there might not be demonstrable attribution of outcomes to the solution itself. Another note of caution is regarding accuracy of data. While many mHealth solutions purport to either capture raw data or to compute various derivative measures, their users and other stakeholders should be cautious of over-reliance and over-confidence on the accuracy of these measures. For instance, sensors that measure a patient's blood pressure or collect an EKG reading may have inherent limitations in accuracy, and moreover may not be well-calibrated to the characteristics of the patient, weather, altitude, or other factors in the measurement environment. Similarly, apps that compute the level of calories burned by a patient, or devices that measure a user's body mass index and bone density may suffer from similar limitations.

To understand the value mHealth technologies provide, the intended impacts must be compared to the actual impacts of these solutions. Some of the case study examples discussed above contain data from clinical trials that point to ease of use and efficacy of such technologies. However, the vast majority of health apps currently available have no clinical data tying the mHealth intervention to better health outcomes. Additionally, developers of mHealth technologies must be aware of how the different configurations of type of technology, level of institutional integration, and function affect these stated aims. For example, if main purpose of the Ovia Pregnancy Tracker app is simply to provide women a way to follow the progress of their pregnancy, the app seems to provide the necessary tools to achieve this aim. However, if this app aims to change healthcare utilization by pregnant women, further institutional integration above and beyond their pilot programs involving health insurers may be necessary. Similarly, if the Mayo Clinic's use of Fitbit trackers is solely to provide a better way for physicians to monitor patients' ambulatory patterns post-surgery, then the technology provides an efficient means to reach these aims. If rather the Mayo Clinic hopes to reduce the length of hospital stay for cardiac surgery recovery patients, utilizing the Fitbit trackers with a patient-focused app may prove useful. This is not to suggest that mHealth technologies must incorporate all aspects of the classification framework at a high level to create value and drive impact. Rather, to reach the desired impact, the appropriate configuration must be determined.

A clarity of intended impact is also required given that the capabilities of these technologies may be immense, but the question of the right patient type for these solutions and the appropriate utilization for these technologies may be unclear. For example, the AliveCor ECG device and app may be used for patients who may suspect a heart arrhythmia but are asymptomatic when they visit the physician. It could also be used for patients with atrial fibrillation to track the effect of different medications or treatments on their condition. However, it is unclear what the main impact the makers of this technology desire. Additionally, although this this technology gives patients the ability to capture their ECG, there is still the question of what they should do with this data. A physician review of the device noted that while anyone could easily use this device, "we did not have a good sense of when (or whether) they *should*" (Misra and Husain 2013). As such, it is difficult to measure what the actual impact of the AliveCor device may be given that the makers of the device do not have a clear positioning for their product.

Conclusion

It is evident that mHealth technologies create value in very diverse ways. Given this range of different types of potential impact, and after studying numerous examples and articles, we have proposed a more detailed framework, specifically for classifying mHealth technologies by type of technology, level of institutional integration, and function. Moreover, in many cases, the potential impact of such technologies may not be easy to identify, to measure, or to attribute it to the technology. Hence the framework ties into the underlying process by which different types of mHealth applications create value. We then applied this classification by reviewing a small number of mHealth applications which have been described in the literature.

The optimal choice and design of mHealth technology will depend on patient population characteristics or the settings in which these technologies are deployed. In resource-limited environments where patients may not have regular access to health care, mobile phone access may nonetheless be prevalent. For example, recent randomized controlled trials in Kenya have shown SMS messaging to be effective in promoting treatment adherence to antiretroviral therapy in patients with HIV. (Horvath et al. 2012) Certain patient populations may exhibit a lower degree of technological friendliness. As such, in certain cases simple text messages interventions may prove more effective than utilizing a smartphone application. Alternatively, patients with access to smartphones who are also relatively tech savvy may respond better to more complex mHealth solutions that agree with their technological temperament. Given the heterogeneity of patient populations and the varying settings in which they reside, health care entities must tailor their mHealth approach to the group they are serving.

Though the proper configuration of type of technology, institutional integration, and function may enable high-value impact from mHealth technologies, there may be barriers to adoption that could also blunt their potential. While platforms, such as Ginger.io, hold to possibility to help patients when they need it most, though passive data collection and behavioral analytics, patients must also be willing to adopt these solutions. Apps such as Ginger.io passively track users' movements, sleep patterns and interaction with technology. While many smartphone owners may already have apps on their phones that collect some of this data and sends it back to app developers, the explicit acknowledgement that this data is being used for medical purposes may make some patients uneasy. However, if users experience enough benefit from these technologies, such as better care or better control of their conditions, this may overcome such barriers to adoption.

With a clarity of intended impact, mHealth technologies, such as Mango Health and BlueStar, hold the potential to create value through adherence to a treatment protocol. Mango Health's platform has increased medication adherence for patients using their app and the BlueStar app has been shown to decrease glycated hemoglobin levels, a key measure of how well diabetes is controlled, in patients using the technology. Given that the BlueStar app is available by prescription only, this also introduces the question of whether these technologies act in similar ways to other prescription therapies, such as medication. For example, do patients who use mHealth technologies exhibit a dose-response to these technologies? That is to say, do patients who use mHealth apps consistently experience better outcomes than those that use them only intermittently? Posed differently, is there a minimum level of user engagement with mHealth technologies required for behavior change? While this question is still unresolved, if this is the case, then tactics employed by apps like Mango Health, such as gamification, may provide a way to increase patient engagement with these technologies and thus better affect health outcomes.

Underlying this suggestion of a positive dose-response to mHealth technologies is the assumption that the more informed a patient is, the better the outcome. However, there may be a level of information at which patients start experiencing diminishing returns from such technologies. If too much information is presented to a patient, they may become lost in the data and also lose the ability to make appropriate health-related decisions. More perniciously, this information may also lead to bad decisions due to overconfidence bias. Looking at data from the financial markets, we find that overconfidence leads individual investors towards high trading levels and a resulting poor performance. (Barber and Odean 2000) Why would we expect patients to make better decisions about their health than their wealth? Recent work on energy efficiency labeling also addresses a similar issue. The literature on better consumer choices through such labeling shows that consumers are “rationally inattentive.” Given this characteristic, the role of information provision is elevated and “it matters what information is provided and how it is provided.” (Davis and Metcalf 2014) If consumers of health care are similarly rationally inattentive, the way information is provided through mHealth technologies will prove critical to their potential to create value for patients, physicians, and the entire healthcare ecosystem.

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