Engaging Pregnant Women in Kenya with a Hybrid Computer-Human SMS Communication System

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ABSTRACT

A growing body of HCI4D research studies the use of SMS communication to deliver health and information services to underserved populations. This paper contributes a novel dimension to this field of study by examining if a hybrid computer-human SMS system can engage pregnant women in Kenya in health-related communication. Our approach leverages the different strengths of *both* the computer and the human. The computer automates the bulk-sending of personalized messages to patients, allowing the human to read patients' replies and respond to those in need of attention. Findings from a 12-month deployment with 100 women show that our approach is capable of engaging the majority of participants in health-related conversations. We show that receiving messages from the system triggers participant communication and the amount of communication increases as participants approach their expected due date. In addition, analysis of participants' messages shows that they often contain sensitive health information conveyed through a complex mixture of languages and 'txting' abbreviations, all of which highlight the benefits of including a human in the workflow. Our findings are relevant for HCI researchers and practitioners interested in understanding or engaging underserved populations.

Author Keywords

HCI4D; ICTD; Maternal Health; SMS; Mobile; mHealth.

INTRODUCTION

The proliferation of mobile devices throughout the world, and particularly in low-income countries such as Kenya, is providing opportunities to create mobile applications that deliver health and information services to people living in poverty. Many of these applications focus on SMS, a low-cost communication channel that is supported on even the most basic mobile phones. However, the majority of existing SMS-based health applications use one-way 'push' messaging, in which generic messages are sent to large numbers of users who have no way to respond [7, 13] or they enable two-way communication between users and a server by requiring that users submit highly-structured messages that can be automatically parsed by the server [5, 16]. Although many SMS-based services would prefer to provide patients with personal attention that takes into account their specific context, they usually employ a small number of health workers who have limited amounts of time to engage in direct communication with individual users. This suggests a need for new approaches that increase the capacity of health workers and allow them to communicate effectively with a larger number of patients.

This paper makes a novel contribution to HCI4D by investigating if a hybrid computer-human SMS system can engage pregnant women in health-related conversations. Unlike prior research, our system leverages the different strengths of *both* the human and the computer and we argue that each plays a critical role in communicating with and engaging patients. The computer automates the bulk sending of personalized, time-specific messages to a large number of patients, which allows the human to spend time reading patients' replies and responding to those that have specific questions or concerns. This approach allows the human to effectively manage a much larger number of patients than would be possible if s/he was required to send all of the messages manually. Moreover, by allowing participants to send unstructured messages to the system in any format or language that they choose, we aim to allow users who may have little experience with SMS to participate and engage with the system.

We evaluate our hybrid approach through a 12-month deployment with 100 pregnant women in Kenya. Pregnant women in Kenya often have to wait for several hours at the clinic to see a nurse [18], which discourages them from attending their antenatal clinic visits and decreases the amount of advice and support that they receive during pregnancy. We use our hybrid SMS system to send pregnant women timely information that is tailored to their specific context and connect them directly to a nurse who is able to respond to their questions or concerns. This research is part of an in-progress randomized controlled trial (RCT) that aims to assess if two-way SMS communication can influence antenatal clinic visits, infant immunization rates and adoption of family planning practices. However, discussing the long-term medical outcomes of the trial is beyond the scope of this paper. Instead, we focus on understanding how low-income women use our computer-human SMS system to engage in health-related communication and we analyze the conversations that are enabled by our approach.

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Key findings from the design and evaluation of our hybrid computer-human SMS system show that, despite most participants having little prior experience with SMS, our approach successfully engages the majority of participants in meaningful health-related conversations. We show that receiving automated messages from the system triggers participant communication and that the amount of communication increases as participants approach their delivery date. Finally, although prior work has presented large-scale quantitative analyses of SMS usage data [8], to the best of our knowledge we contribute the first in-depth analysis of unstructured SMS conversations with low-income women in Kenya. We show that participants used a complex mixture of languages and 'txting' abbreviations to communicate highly personal health information over SMS. Taken together, these findings suggest that our hybrid computer-human SMS system has the potential to engage users in meaningful health-related communication.

BACKGROUND AND RELATED WORK

Our work contributes to a growing body of HCI4D literature that focuses on using SMS to communicate with users in underserved communities. The low cost of SMS compared to voice means that SMS is currently the preferred communication channel for much of Africa, including Kenya [12].

One-Way SMS Communication

A large number of prior studies have focused on one-way communication in which a server sends bulk SMS messages to a large number of recipients. Reminder systems fall under this category, including solutions designed to increase medication adherence [15], reduce missed clinic visits [13], or increase the timeliness of health worker home visits [7]. However, a major disadvantage of these systems is that the recipients have no way to send messages back to the system. For example, in one study health workers still received reminders to visit patients that had moved away from the area [7].

Another class of one-way SMS systems allow users to submit data to a server. In most cases, submitted messages must conform to a specific structure to enable automated parsing by the system. This model has been used to report stock levels [2], communicate diagnostic test results [1] or submit data [19]. However, several of these studies find that users struggle to compose properly structured messages and frequently make mistakes [19]. To overcome this limitation, other systems allow users to submit unstructured messages and then employ complex server-side processing to try and make sense of the messages. For example, Ushahidi [17] used server-side natural language processing to try and decipher submitted messages, while Hellström et al. [9] used crowdsourcing to enable users to report election incidents by SMS. However, these systems do not provide feedback to users and participants reported not using the system because they had no idea if the information they submitted made any difference [9].

Two-Way SMS Communication

To overcome the lack of feedback provided by one-way systems, several projects have designed two-way user-server SMS platforms in which users submit structured queries to a server and receive automated responses. This model has been deployed to provide users with health [16], education [5], and agricultural [23] information. However, as with one-way systems that use structured messages, many of these projects report high error rates in the messages submitted to the system. Moreover, training users to compose formatted messages is challenging and hampers the scalability of these systems.

Other systems enable two-way communication between human users. One particularly relevant example is the Weltel study [14], in which a health worker manually sent a single word message to participants who were required to respond with a single word answer. Participants that did not respond received a telephone call from the health worker. The study results show that patients who received messages had improved HIV medication adherence and lower viral loads than a control group. However, the health worker needed to manually send 273 messages and call roughly 30% of participants each week, with 62% of calls unanswered [22]. By using our hybrid SMS system, we are able to send longer, informative messages, reduce the health worker's workload, and enable meaningful SMS conversations between the health worker and participants.

Densmore [6] describes a bulk SMS platform designed to improve an NGO's communications with its clients. The system shares some similarities with our system in that it can be used to send messages to groups of users who may respond. However, unlike our system, which automatically sends tailored messages to participants at appropriate times, all of the messages in Densmore's study were manually initiated by NGO employees. In addition, all of the message senders and recipients were skilled professionals or NGO employees. Our research shows communication with low-income women drawn from the general population of Kenya, who have unknown backgrounds and varied experience with technology.

Perhaps the closest match to our hybrid human-computer communication model are 'human-in-the-loop' systems that require the input of both humans and machines. Prahalad [20] and Joshi [11] have proposed such systems in the context of rural banking and other global development efforts, though not in relation to user engagement or SMS communication.

Existing SMS Platforms

Several open-source platforms have been developed in recent years that enable the creation of SMS-based applications in low-resource environments, including FrontlineSMS[1] and RapidSMS[2]. These platforms have been widely used for a variety of applications that primarily require one-way or highly-structured two-way communication. In designing our hybrid SMS system for this study, we needed an automated solution capable of sending tailored, time-specific and dynamic messages to different groups of participants, coupled with an administrative user interface that allows a human to moderate conversations and respond to participant communication. At the time, neither FrontlineSMS nor RapidSMS supported this functionality and so we built our own prototype. However,

[1] FrontlineSMS: http://www.frontlinesms.com
[2] RapidSMS: https://www.rapidsms.org

we do not intend for our prototype to compete with these existing systems. Instead, we anticipate that they could incorporate our hybrid approach, which would allow their users to create SMS applications that better support user engagement and more nuanced communication with target populations.

A HYBRID COMPUTER-HUMAN SMS SYSTEM

The goal of our work is to use a hybrid computer-human SMS system to engage pregnant women in Kenya in health-related communication. Designing an SMS messaging system that is appropriate for maternal health settings requires that we take into account a complex and nuanced set of design criteria. For example, the date at which a woman is predicted to give birth and the date at which she actually gives birth can vary by several weeks. As a result, it is often impossible to accurately predict when a woman will give birth and automatically switch her from antenatal to postpartum messaging. To overcome challenges like this, our hybrid SMS system has been designed to incorporate input from *both* a human nurse and automated software, with each playing a critical role in the resulting communication.

Design

At a high-level, our approach allows automated SMS scheduling software to handle the majority of outgoing messages. This greatly reduces the total number of messages that the nurse is required to manage, allowing her to instead spend time reading and responding to unstructured messages submitted by participants. In this way, the nurse is able to effectively communicate with a larger number of patients than would be possible if she had to send all of the messages manually. Keeping in mind the challenges of designing for maternal health settings, we identified the following criteria that influenced the design of our system:

Personalize messages

As much as possible, we personalize the content of the messages to each individual woman's specific context. We send messages that take into account gestational age and provide tailored message tracks for groups of participants with special circumstances, such as first time mothers, adolescent mothers, or women who have had previous cesarean sections. Moreover, we allow participants to choose the language (English or Swahili) that they receive messages in, and the day of the week and time of day that the messages arrive.

Encourage engagement

Our approach encourages women to engage with the system in several ways. First, each message includes a simple question relevant to the informational content of the message. Answering the question provides a natural method for engagement. Second, messages that women send to the system do not have to be structured or specially formatted in any way. Instead, women can submit questions, concerns or updates in any format and in whatever language they prefer.

Provide professional health care

Since we cannot predict the nature or content of the messages that women send to the system, it is important that responses come from qualified health professional familiar with the local culture and language. Moreover, the information in the automated messages was carefully crafted by maternal and child health experts to ensure that it was both relevant and medically accurate. Connecting underserved women directly to a health professional was one of our major goals.

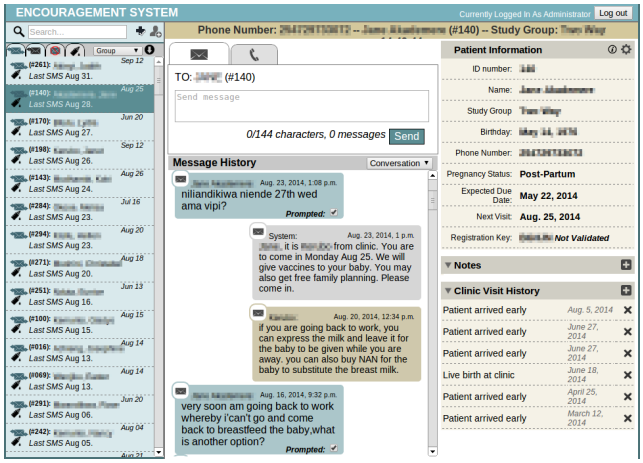

Figure 1. The laptop-based interface that the nurse uses to manage all participant communication. The system has a list of searchable contacts on the left, the communication history of the currently selected participant in the center, and mechanisms for tracking the participant's visit history and health status on the right

Increase the nurse's capacity

To allow the nurse to easily communicate with a large number of women we designed a laptop-based interface that provides a portal through which the nurse can view and reply to messages (see Figure 1). The center of the interface depicts messages that have been sent and received by the selected participant as a conversation. Messages from the system, the nurse and the participant are displayed in different colors so that it is easy to interpret the participant's communication history. At the top of the interface is an input box that the nurse can use to send messages to the participant. The left side of the interface provides a searchable list of participants with new messages filtered to the top of the list. This allows the nurse to quickly locate and view unread messages that she has not yet responded to. Finally, the right side of the screen displays the participant's visit history and health status, such as her next scheduled clinic visit or when she is expected to give birth. Using this interface, the nurse can quickly understand a patient's prior communication, visit history and medical context and personalize her responses accordingly.

Adapt to participant circumstances

The unpredictable nature of pregnancy means that the sequence of outgoing messages may need to be dynamically adjusted based on a participant's changing circumstances. For example, if a woman gives birth earlier than expected, we need to be able to change the messages that she is receiving accordingly. Thus, rather than defining a fixed set of messages to be sent at sign-up, the messages sent to participants are instead dynamically selected according to each woman's current status at the time of sending. If the nurse changes the status of a woman in the system, the messages that she receives will automatically adapt to her new status.

Allow participants to respond only when they want to
Several prior studies [7, 14] used escalating reminder systems in which participants received a telephone call when they did not respond to a message. Our original design emulated this model. Initially, if a participant did not respond to a message, the message would be repeated every 48 hours for four days until a response was received. If no response had been received at that point, the system would prompt the nurse to call the participant. However, early feedback from focus groups with health workers and pregnant women revealed that this interaction model was overly demanding, and we changed our design to allow participants to only respond to messages when it made sense to them.

Message Content and Timing

The content of the SMS messages sent to participants was carefully crafted by maternal and child health experts using Kenya's antenatal care guidelines. In addition, we conducted focus groups with 22 pregnant women and 10 health workers prior to the start of the study to obtain feedback and iterate on the message content. Findings from these focus groups suggested that participants really wanted to feel as though someone cared about them. In addition, they wanted the messages to be directed specifically to them and take into account their personal situation. To achieve these goals, we designed the message content to include the name of the participant, with each message appearing as if it came from the study nurse (see Table 1). The messages were then further tailored to each participant based on her specific expected delivery date and covered a range of health and pregnancy related topics, including birth preparedness, factual information on what to expect, family planning, breastfeeding and immunization. The messages were then further personalized based on the participant's current pregnancy status, such as being a first time mother or adolescent. Finally, as shown in Table 1, each message that was sent by the system included a specific question designed to encourage the participant to respond.

Based on each participant's specific criteria, the system automatically selected and dispatched the relevant preprogrammed message at the appropriate time. In several cases, the final automated message was longer than the maximum size of a single SMS (140 characters) and was broken into two messages that were sent at the same time (see Table 1(b) for an example). In addition to health related information, participants also received automated appointment reminders two days before each scheduled clinic appointment (see Table 1(c)). Messages were also sent on the day of enrollment, on the day a clinic visit was recorded, and when a delivery was recorded.

Finally, women's delivery dates in Kenya are typically calculated based on the date of their last menstrual period. However, this method is frequently inaccurate and, in reality, they give birth anywhere from several weeks before to several weeks after their predicted date of delivery. Thus, if a participant had not given birth by the time all of the scheduled antenatal messages had been sent, the final antenatal message was repeated for an additional two weeks or until a birth was recorded in the system, at which point they began receiving tailored postpartum messages. In total, each participant that completed the study received approximately 35 automated messages in the seven to eight months between enrollment and completion, with at most two system messages per week.

(a) Automated message at 27 weeks pregnant [Name], this is [Nurse] from clinic. Iron helps carry nutrition to your baby. If it is low, you feel tired. Are you taking iron or do you need tablets?
(b) Automated message 8 weeks after giving birth (1) [Name] this is [Nurse] from clinic. Are you having trouble breastfeeding? Giving the baby other fluids can cause illness and weakness. (2) Please continue to only give breast milk to your baby for at least six months. How long do you plan to breastfeed?
(c) Automated clinic appointment reminder [Name], it is [Nurse] from clinic. You are to come in Friday Aug 08. We will give vaccines to your baby. You may also get free family planning. Please come in.

Table 1. Examples of automated messages sent by the system at (a) 27 weeks pregnant; (b) 8 weeks after birth; and (c) 2 days before a scheduled clinic visit. Note that, as is the case for (b), any messages longer than 140 characters were sent in two parts.

Implementation

Our system is a python-based Django web application that connects to the Kenyan telecommunication system through Shujaa Solutions[3], a third party SMS gateway that provides an API that our server can use to post outgoing messages. Incoming messages from participants are routed to our server via a callback URL. In addition, by establishing a reverse billing five-digit short code, we were able to to allow participants to send and receive messages free of charge.

EVALUATION

To understand women's engagement with our hybrid SMS system, we analyzed messages sent during a year long deployment with 100 pregnant women in Kenya. Our work is part of Mobile WACh, a larger IRB-approved clinical trial investigating maternal mobile health initiatives and behavior change. The deployment was based at Mathare North Health Center, a city council clinic located approximately 10km from Nairobi, the capital city of Kenya. Mathare provides basic health services to patients, including normal antenatal services for pregnant women, but refers all complicated cases to a higher level health facility.

Study Nurse

A dedicated nurse was hired for the duration of the study to enroll participants, respond to SMSs, keep track of anticipated and completed patient visits, monitor when participants gave birth, and conduct post study surveys. The nurse was female, computer literate and had experience reading and responding to email and participating in Skype conversations.

[3] Shujaa Solutions: http://shujaa.co.ke

We provided the nurse with a laptop and access to the system management portal so that she could communicate with participants. Prior to the start of the study, the nurse received roughly two hours of training on how to use the software.

Participant Enrollment

Starting in August 2013, pregnant women visiting the clinic for their first or second antenatal visit were invited to participate in the study. Volunteers needed to have personal or shared access to a mobile phone, be able to read and respond to messages in English or Swahili (the two national languages of Kenya) and be planning to reside in the area for the duration of their pregnancy. In addition, due to technical limitations of the SMS gateway, participants were required to possess a SIM card for the telecommunications provider Safaricom. Fortunately, the majority of Kenyans already use Safaricom. During the entire study only two people failed to meet the inclusion criteria, and this was because they did not possess a Safaricom SIM card. In total, we enrolled 100 women to receive messages from our hybrid SMS system. All participants sent and received messages using their own personal or shared mobile phones. During enrollment the nurse explained that participants would not be charged for any messages sent to the five-digit study number. All participants received a small monetary compensation for their participation.

Procedure

After screening volunteers and obtaining informed consent, the study nurse conducted a structured interview with each participant in which she collected the participant's demographic information, medical history, and current usage of and prior experience with technology. She also collected their mobile phone number and explained that they would receive one to two messages per week, starting at 20 weeks of pregnancy and continuing until 10 weeks postpartum. She explained that the messages would contain questions about their health and that they should respond, although she also made it clear that they should not use the service for emergencies. Each participant also received a business card that contained the study's five-digit short-code. After enrollment, the study nurse did not meet with participants again until several weeks after they had given birth, although participants did see other clinic nurses when they attended their normal antenatal appointments. All participant communication with the study nurse was through participants' personal mobile phones.

Data Collection and Analysis

The goal of our paper is to investigate if we are able to engage pregnant women using our hybrid computer-human SMS system and to characterize the resulting conversations that take place. To achieve this goal, we analyzed data from 100 structured interviews conducted with participants at enrollment, 3661 automated messages sent by the system, 423 messages sent by the nurse and 944 messages sent by participants, and data from two 45-minute semi-structured interviews with the study nurse that were conducted over Skype.

We began by examining the data from interviews conducted at enrollment and characterized the population of women that participated in our study, organizing them according to age, income, language, education level, employment, and their current usage of and prior experience with technology. Following this, we conducted an iterative, in-depth analysis of messages that participants sent to the system. We began by noting the language that participants sent messages in (English, Swahili or a mixture) and whether each message contained abbreviations or 'txting'. One of the authors, who speaks Swahili, translated any messages that were in Swahili into English. Then, we coded any messages that (1) answered a question posed by the system; (2) answered a question posed by the study nurse; (3) asked a question related to information sent by the system; (4) asked a new question that was not related to anything sent by the system; and (5) provided the nurse with an unprompted update or information. We further identified any messages that formed a 'conversation', which we define as a back-and-forth sequence of at least two related messages. For each identified conversation, we then further analyzed the messages that made up the conversation to identify who initiated the conversation (the system or the participant) and any themes, events or topics that caused participants to engage in conversation.

FINDINGS

Understanding Our Participants

Before analyzing participant engagement with the system, it is important to understand the characteristics of the women in our study and their prior experience with technology.

Demographic Characteristics

Our participants were all pregnant women aged between 16 and 37 years (M=24.1, SD=4.6). 38 participants reported that they had attended primary school, 51 had started (but not necessarily finished) secondary school, while 11 had some form of post-secondary education. The majority of Kenyans in Nairobi speak a complex combination of Swahili, English, slang words and local languages known as Sheng. However, since the language of education and government in Kenya is English, most of our participants prefer to receive formal communication in English as opposed to Swahili, and 97 participants chose to receive SMS messages in English. 86 participants reported that they live in single-room houses, 94 within 10km of the clinic, and 88 walked to the clinic for their appointment. 85 participants said that they were self-employed or housewives with family sizes ranging from 2 to 6 people (M=3.1, SD=1.3) with a mean monthly household income of 6500 (SD=3728) Kenyan shillings (roughly US$73). These characteristics suggest that, despite living close to Nairobi, Kenya's capital city, many of our participants are living in extreme poverty [21].

Experience with Technology

Access to mobile technology in Kenya has expanded exponentially over the past decade. All of the women screened for our study had access to a mobile phone. 76 reported that they possess their own mobile phone, while the other 24 shared a mobile phone, usually with their husband. Despite this widespread access to mobile technology, only 34 participants self-reported that they use SMS regularly, with 16 reporting that they do not use SMS at all. Moreover, only 7 participants reported ever having used the Internet. By contrast, 90% of

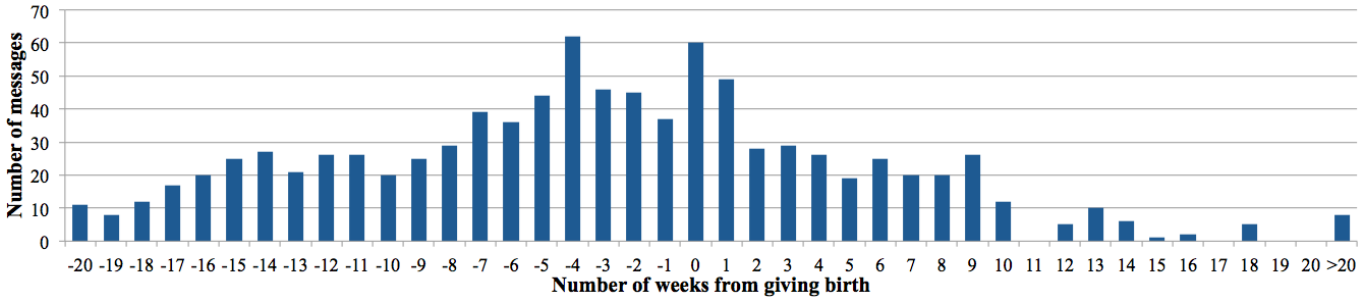

Figure 2. Total number of messages sent during each week before and after delivery. Week 0 corresponds to the week in which participants were recorded as giving birth. Week -5 depicts five weeks before giving birth while 5 shows five weeks after giving birth

participants do use their mobile phones to access mPesa, Safaricom's mobile banking service. Since mPesa requires users to navigate text-based menus and enter data, we anticipated that participants would be able to send and receive SMS messages even if they were not already frequent SMS users.

Measuring Participant Engagement

We use the number of messages that participants sent to the system as our measure of engagement. Thus, women who communicate more by sending more messages have a higher level of engagement. The total number of weeks that participants received messages from the system varied according to when they enrolled in the study and when they gave birth. To account for this variance, we divided the total number of messages that each participant sent by the number of weeks that they were receiving messages to obtain our final engagement metric, which we report as the average number of messages that each participant sent per week of participation.

The majority of participants engaged with the system

Between August 23, 2013 and August 31, 2014 we received a total of 944 SMS messages from participants. During the same time period, the system sent 3661 automated messages and the study nurse sent 423 messages to participants. On average, each participant sent 0.46 (M=0.26 SD=0.54) messages per week or two messages per month for the 7-8 months that they participated in the study, with 73 of our 100 participants sending at least one message. In addition, many participants communicated on a regular basis throughout the study (see Figure 2) with the highest amounts of engagement recorded during weeks close to participants' delivery dates. This high level of participant engagement is encouraging, particularly since the majority of our participants did not have much experience with SMS and prior work has struggled to engage these kinds of users with SMS communication [4].

Participants were more engaged close to their delivery date

To analyze how participants' communication varied throughout pregnancy, we calculated the total number of messages that participants sent in relation to when they gave birth. Our findings are shown in Figure 2. Week 0 in the graph shows the week that participants were recorded as giving birth, with values before 0 showing weeks before giving birth and values after 0 showing weeks after giving birth.

In general, participants' engagement with the system increased as they approached their delivery date. This suggests that participants were more motivated to communicate the closer that they were to giving birth. In addition, the questions that the system sent to participants in the third and fourth weeks prior to their expected delivery date specifically asked, *"Are you worried?"* and *"Do you have any questions about where to go in labor and how to get there?"* Similar open-ended questions were asked in other automated messages, however, they elicited the most responses in the weeks just prior to delivery, which indicates that this was an opportune time to provide participants with someone to whom they could direct their questions or concerns about the process of giving birth. After delivery, the number of messages that participants sent gradually decreased again, with a notable drop in messages submitted more than 10 weeks after birth. Since participants stopped receiving messages from the system at 10 weeks postpartum, it makes sense that, for the most part, they also stopped sending messages to the system.

Receiving messages triggered engagement

Figure 3 shows when participants sent messages to the system in relation to when they received messages from the system. The vast majority of messages sent by participants were on the same calendar day as they received a message from the system (705 out of a total of 944). A large number of these were direct responses to questions that the system had asked. However, many also triggered additional questions unrelated to those posed by the system, with 39 different users each submitting at least one new question. For example, one participant received the following automated message:

> *"[Name][4] this is [Nurse] from Mathare clinic. Regular, strong stomach pains are a sign of labor. If you feel strong tightening of your belly, leaking of fluid or any bleeding go to the clinic. Have you had any labor pains? How often do you feel them? Are you worried?"*

40 minutes after receiving this message, the participant sent[5],

> *"Hi,am not as such worried,but i have a little fear.i have never had any labor pains."*

[4] All names have been removed to preserve anonymity.

[5] All messages quoted in the paper show participants' original spelling and grammar.

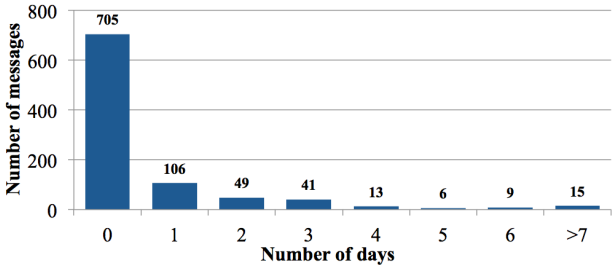

Figure 3. Summary of when participants sent messages to the system in relation to when they received messages. A value of 0 days means that the participant sent a message on the same day as receiving a message.

Then, ten minutes after sending her initial response, she sent another message to the system,

> *"Hi.madam [nurse],kindly will u state for me items that are needed when i will attend clinic during labor pains e.g clothing for the baby,basin,.and what els....."*

to which the nurse then responded,

> *"Hi [name], you need baby clothes, shawl, leso, basin, spirit, cotton wool. that is mainly it. the rest you can inquire from the nurses when you reach the hospital."*

Exchanges like this suggest that receiving messages from the system reminded participants that they had someone to whom they could direct their questions or concerns and highlight the potential for the automated messages to trigger engagement.

Some participants did not respond

Twenty-seven participants did not engage in any communication during the study. We tried to contact these participants to understand some of the reasons for their lack of response and were able to successfully reach eight participants. Three explained that they shared a phone with their husband, which made it difficult for them to read and respond to the messages. In one case, a participant said that her husband deleted the messages before she had a chance to read them. In several other cases, the person who answered the call told us that the participant had changed their phone number during the study. Moreover, several of the phone numbers that participants had provided to us appeared to be incorrect, with the number either not being a valid phone number or with the person who answered the call claiming to not know the participant.

Understanding Participants' Use of Language

Kenya has two national languages, English and Swahili, and we wanted to understand participants' use of these languages in their messages. Our findings show that participants' messages frequently included a complex mix of English, Swahili and Sheng (an informal mixture of the two), 'txt' abbreviations, and numerous spelling and grammatical errors, all of which highlight the benefit of having a human interpret and respond to messages.

Participants sent messages in a mixture of languages

Since 97 participants chose to receive messages in English, it makes sense that the majority of messages sent to the system (784 out of 944) were also in English. However, since only three participants chose to receive messages in Swahili, we were surprised to find that 41 participants sent messages that contained at least some Swahili, with 13 communicating entirely in Swahili. Follow-up conversations with the nurse showed that although some participants were more comfortable with Swahili, they feared that the messages would contain formal Swahili rather than the colloquial language that they typically use. A total of 73 participant messages were entirely in Swahili and a further 87 contained a mixture of Swahili and English. Our analysis of these messages suggests that participants mix Swahili and English freely, choosing whichever word comes to mind first. For example,

> *"my headache is ve ly pain and kizuguzugu"*

The word 'kizuguzugu' (a misspelling of 'kizunguzungu') means 'dizzy' and, although we cannot be sure, we hypothesize that this participant was either unsure of the English word for dizzy, or simply more familiar with the word in Swahili. Other participants more blatantly used Sheng, mixing English and Swahili whenever was convenient and incorporating new words not pulled from either language:

> *"My nxt visit will be on 29th may.na nina sweat sana siku hizi xana xana usiku.can u elaborate on this pliz"*

The Swahili part of this message means 'I am sweating a lot these days a lot a lot at night'. The first time the participant writes 'a lot' in Swahili, but the second and third time it is written in the slang version commonly used in Sheng. Although this complex mixing of languages may be understood by a bilingual Kenyan, it would be extremely difficult for any language processing software to interpret these messages.

Participants frequently used 'txt' abbreviations

'Txting' refers to the use of abbreviations and other techniques to craft SMS messages, often with the aim of reducing the overall length of the message [3]. Analysis of our participants' messages shows that 30% or 287 messages used 'txting' that often made the messages difficult to interpret:

> *"the 1st thing iwould like 2say hi 2u hpng dat ur fine.my qstn is dat when ivisted clnc last mnth itryd 2expose my complication 2the dctr dat the lab told 2hav some medicine coz of infctn bt they gav out 2 me some amoxil capsols 4me 2use 2x3 pa day bt whn iused them 4the 1st 4day iwas flng stomach strng pain den ijust chsn my self 2surender tkng thm did iwrng or icld cntnu usng them bcz its how they use 2cure"*

In addition, several participants appeared to not know how to input certain characters into their phone. For example, one participant responded to a question about heartburn with,

> *"yesiamhavingheartburninaweekitocurstwice"*

These findings suggest that many participants would find it difficult to compose messages that required specific formatting and it is an advantage that our system allows participants to send unstructured messages. In addition, the mix of language, 'txting', and errors highlights the importance of considering the cultural and linguistic context for automated messages and human replies.

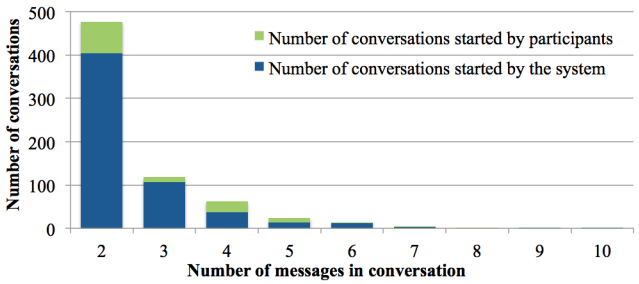

Figure 4. Graph showing the number and length of conversations (two or more related messages) started by the system and by participants.

Understanding the SMS Conversations

To understand the conversations that arose from participants' engagement with the system, we labeled any sequence of two or more related messages as a 'conversation' and analyzed the length and content of these conversations. In total, we recorded 703 conversations that took place during the study, ranging in length from two to ten messages (see Figure 4). 529 conversations were initiated by automated system messages, while the other 124 were initiated by participants.

Conversations with two messages: question and answer

The majority of two-message conversations fall into two categories: (1) the automated message asks a question and the participant responds, and (2) the participant asks a question and the nurse responds. Participant responses to system questions ranged in length and complexity from simple *'yes'* and *'no'* answers to longer, in-depth updates, such as,

> *"Am not having heartburn but am having alot of pain at the side of stormach and at the back.sometime it enter in the legs that i cant even make a single step till the pain disapear.then there is something coming up from stomach such as am unable to breath."*

There were 73 additional questions posed by participants that the nurse was able to answer with a single message. Many of these questions demonstrate the value of connecting participants to a health professional. One message asked,

> *"I have a question that is disturbing me, can a pregnant woman be dewarmed?"*

while another inquired,

> *"Hey [nurse] i ga ve birth on satudy bt my bby is cryng of stomac is it advaisable i giv ha medicine?"*

It is unlikely that these participants would be willing to wait in line for hours at the clinic just to ask these kinds of questions, which suggests that our system successfully lowers the barrier between our participants and health-related information.

Conversations with three or more messages

The majority of conversations longer than two messages were initiated by the system and then continued by the participant and the nurse. In many cases, participants would respond to a system question with a related question. For example,

> **System:** *"[Name] this is [Nurse] from Mathare clinic. When you come in for labor, we will give you a birth notification for the baby. Delivery at the hospital could save your baby's life. Do you have any questions about where to go in labor and how to get there?"*
> **Participant:** *"My worry is how 2 get in the hosp. Becoz of insecurity in our area incase labor starts at midnight. Another question is when i get at the hosp. 4 example at mathare at midnight will they able 2 open 4 me?"*
> **Nurse:** *"Hi [name], This is [nurse]. The maternity unit at Mathare operates for 24 hrs a day, so if you go there at midnight they will definitely attend to you. Thank you."*

This highlights the value of including carefully crafted questions in the automated messages that encourage participants to share their questions and concerns. Other conversations took place solely between a participant and the nurse. In these cases, a participant usually contacted the nurse seeking additional information or advice. For example,

> **Participant:** *"how about if i'give the baby other liquids,like cow milk what will happen?"*
> **Nurse:** *"Hi [name]. How old is your baby? If the baby is below 6 months, we advise you give only breast milk because the baby's digestive system is not yet fully developed to digest other foods. If i may ask. Why do you want to give cows milk?"*
> **Participant:** *"she is almost three months. very soon am going back to work whereby i'can't go and come back to breastfeed the baby,what is another option?"*
> **Nurse:** *"if you are going back to work, you can express the milk and leave it for the baby to be given while you are away. you can also buy NAN for the baby to substitute the breast milk."*

The longest conversation that we identified consisted of 10 messages in which the participant asked four different questions that were answered by the nurse. After receiving her answers, the participant concluded the conversation with,

> *"Thanks alot. Those are some of the questions that were really bothering me."*

Participants communicated sensitive personal information

Our analysis of participants' communication revealed that many were willing to communicate deeply personal health information over SMS. Several participants inquired about sexually transmitted diseases:

> *"i'was tested 4 siphilis on monday.is it posible someone can stil have other std?"*

while others asked if it was safe for them to have sex:

> *"Hi [nurse],am gud since we were 2getha.just wanted 2 ask u whetha a baby can b affected by sex while in the womb apart from sexual transmitted diseases."*

Interestingly, some participants communicated sensitive information through updates without asking a specific question:

> *"Thanks a lot.I don't have pains nor bleeding. If I can cough or sneeze I notice little urine come out. Am satisfied in early stage is okey. Am greatful for your concern."*

Participants' willingness to communicate this personal information over SMS has several potential implications. For example, since participants may be hesitant to talk about embarrassing or sensitive topics in person [10] the SMS system could provide them with a more comfortable communication channel for airing their concerns. Finally, many participants expressed gratitude for the support that they received:

> *"Dank U 2, 4 Being Consern About My Health. Am Not Realy Bad, But We R Stil Struggling With Life & Pray 2 Survive It. Coz 4 Me It's Had."*

These messages are particularly rewarding because they were unsolicited, which gives us reason to believe that participants were genuinely grateful and that it made a difference to them to feel as if someone cared about them.

Some participant questions went unanswered

For our hybrid computer-human SMS system to be successful, it is crucial that the nurse is also engaged and sends timely responses to participants (although we made it clear during enrollment that participants should *not* use the system as an emergency service). Our analysis of participant messages revealed a total of 50 questions that were never answered. In addition, in some cases the nurse responded several days after the message was received. Although the nurse's lack of response to messages did not have any observable effect on participant engagement, we plan to change the design of the interface to help the nurse do a better job of responding to messages. First, although the software made it easy to see unread messages, the nurse would often read a message but not respond immediately. However, after reading messages, it was difficult to keep track of messages that she had read but not responded to. To overcome this challenge, we plan to change the design of the system management portal so that, in addition to highlighting unread messages, it also flags messages that have not yet received a response. The nurse also described that she feared the laptop would get stolen if she carried it on public transit or left it at the clinic overnight. Thus, she frequently left the laptop at home when she went to the clinic for the day and was then unable to read and respond to messages until she got home in the evening. To overcome this issue, we plan to design a mobile version of the software that the nurse can use to read and respond to messages at any location using her personal Android phone.

DISCUSSION

Our findings clearly demonstrate the potential for hybrid computer-human SMS systems like ours to engage women in health-related communication during pregnancy and postpartum. We believe the success of our approach relies on the contributions of *both* the computer and the human. Since participants only met the nurse once at enrollment, we argue that it is not only the personal face-to-face connection to the nurse that causes them to engage with the system. Rather, it is the combination of carefully crafted personalized messages, the perceived relationship with the 'nurse' created by the automated messages *and* the messages sent by the nurse, each of which contribute to participants' motivation to communicate. The streamlined, tailored system messages provided a foundation on which further communication was built, and participants' responses to these messages suggest that they perceived the automated messages to come directly from the nurse rather than an automated system. With the system automating the bulk of the sending, the human was able to fulfill the higher order demands for advice and person-specific care. In addition, the varied topics and questions messaged by participants and the unpredictable nature of pregnancy motivate the need for a human to dynamically and adeptly control the messages that are sent. Participants often asked sensitive medical questions that require a trained professional to answer or triage to higher-level in-person care.

Taken together, these findings suggest that our system is able to supplement currently overstretched health care systems in a meaningful way. Not only do hybrid systems like ours allow for health education, appointment reminders and information dissemination, they may engage women in their own care, creating more informed patients and allowing for triage of both necessary and unnecessary in-person clinic visits. Moreover, enabling this communication requires little in terms of direct or indirect costs to the participant (*e.g.*, no travel time, transportation, waiting to see a nurse) and may decrease unnecessary visits to the clinic, which could help to reduce clinic waiting times for all patients.

The use of a hybrid messaging system does raise an interesting ethical debate: participants may think that the automated messages are being personally composed by the nurse. Our hybrid design is a compromise between an entirely automated system and a manual one. We use technology to efficiently accomplish what a human could do manually without significantly changing the process or workflow. Moreover, in our case, the outgoing automated messages have been carefully crafted by global health experts and tailored to each participant's health status. In addition, all participant messages and questions are reviewed and responded to by a qualified nurse. We believe that this approach is ethically acceptable, allowing underserved women to receive personal advice from a trained health professional, which would not be feasible if the nurse had to send all of the automated messages manually.

Our study also exposed several interesting design opportunities that we plan to explore. For example, we would like to make it easier for nurses to keep track of questions sent by women. One potential approach could be to model the web-based interface as a 'ticket management system' or email client instead of using an SMS-focused paradigm. Another interesting addition would be to allow the nurse to create and save template responses to frequently asked questions. For example, several participants asked about hospital operating hours, the safety of eating particular foods, vaccine schedules *etc*. Having template answers to these questions may help the nurse to respond more quickly and efficiently.

As we consider how to scale our hybrid system to larger deployments, we need to carefully consider how best to preserve the privacy of patients' personal health data. In our study, we explained that participants would receive messages on their own phones and we allowed them to choose the time of day that messages would arrive in part to allow them to choose a time when they would likely be alone. To avoid accidentally

revealing a woman's pregnancy to her husband or family, we only began sending messages at 20 weeks of pregnancy. At the clinic, access to the messages was limited to the study nurse who logged in with a password. We hope to learn more about patients opinions on privacy through follow-up interviews at the conclusion of the ongoing medical study.

Finally, an important consideration in any HCI4D project is the sustainability of the system. Since women were able to send messages to the system for free, we are unable to tell how engagement would change if women had to pay for messages. The cost of each incoming or outgoing SMS was US$0.03. We paid for a total of 5028 messages, costing a total of US$150.84. Our biggest cost was a US$300 monthly fee to keep the SMS gateway open. However, this is a fixed fee that will not increase as the system is scaled up which means that (at least for the foreseeable future) the cost per participant will decrease as the number of participants increases. Another limitation of our study is that it involved a single nurse who managed all 100 participants at a single study site. We anticipate that additional challenges will arise as we scale the system to a large number of clinics and health workers.

CONCLUSION

This paper describes a hybrid computer-human SMS system that we designed to encourage pregnant women in Kenya to engage in health-related communication. Findings from a 12-month deployment of the system involving 100 pregnant women show that the system successfully engages the majority of participants by leveraging the different strengths of *both* the computer and the human. Moreover, analysis of the resulting conversations that took place between the system, the nurse and participants suggest that our hybrid approach provides a valuable communication channel that connects pregnant women directly to a qualified health professional. Taken together, our findings contribute a valuable and novel dimension to the growing body of HCI4D research that aims to understand and engage underserved populations.

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