# e-IMCI: Improving Pediatric Health Care in Low-Income Countries

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**ABSTRACT**

*Every year almost 10 million children die before reaching the age of five despite the fact that two-thirds of these deaths could be prevented by effective low-cost interventions. To combat this, the World Health Organization (WHO) and UNICEF developed the Integrated Management of Childhood Illness (IMCI) treatment algorithms.*

*In Tanzania, IMCI is the national policy for the treatment of childhood illness. This paper describes e-IMCI, a system for administering the IMCI protocol using a PDA. Our preliminary investigation in rural Tanzania suggests that e-IMCI is almost as fast as the common practice and potentially improves care by increasing adherence to the IMCI protocols. Additionally, we found clinicians could quickly be trained to use e-IMCI and were very enthusiastic about using it in the future.*

**Author Keywords**

*IMCI, Tanzania, child health, PDA, automation*

**ACM Classification Keywords**

*H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.*


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## INTRODUCTION

Recent advances in mobile technology have made it practical to automate some aspects of health care delivery in low-income countries. The urgency of this effort is underscored by the unprecedented health inequities that exist between today's poor and wealthy populations. In low-income countries, almost 10% of infants die during their first year, compared to 0.5% in wealthy countries [7]. Approximately 9.7 million children under-five years of age die each year in poor countries, where much of the population lacks access to safe water, sufficient nutrition, or well-trained health workers [4]. While extreme poverty is the underlying cause of these deaths, the immediate cause for a large percentage are just a few diseases—malaria, pneumonia, diarrhea, measles—all of which can be treated easily and inexpensively in their early stages [11].

The national standard in Tanzania, as in many countries, for a child presenting with symptoms of these diseases is to follow the Integrated Management of Childhood Illness (IMCI) protocols. IMCI specifies a series of investigations (e.g., take respiratory rate, check for sunken eyes, ask if fever has been present every day, etc.) for each complaint, and a treatment is determined based on the results of those investigations. While IMCI in Tanzania has been shown to lead to rapid gains in child survival when correctly applied [2], the use of IMCI is limited by the expense of training, the lack of sufficient supervision, the time it takes to follow the IMCI chart booklet and the tendency to adhere to protocols less rigorously over time.

To address these barriers, we have developed and piloted e-IMCI, a program that runs on a PDA and guides a health worker step-by-step through the IMCI treatment algorithm. There are many potential benefits of e-IMCI compared to

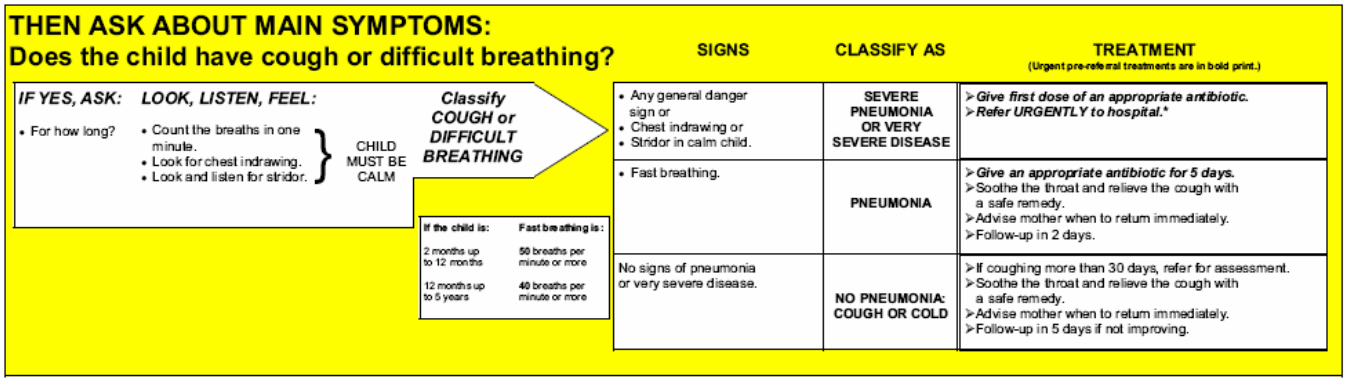


**Figure 1: IMCI flowchart for child with cough or difficulty breathing.**

the current paper-based approach. We expect improved efficiency and adherence with less training. e-IMCI can reduce skipped steps, branching-logic errors, and miscalculations. In addition, training time can be reduced because the algorithm itself does not need to be as rigorously taught. Since the software automatically navigates through the IMCI chart, we expect it to be more efficient than paper-based methods where the clinician must determine the next question. Additionally, more sophisticated protocols can be deployed, as the design of IMCI was constrained by what could be practically included in paper flipcharts. Similarly, updating electronic protocols is much easier than paper ones.[1] Finally, the data from e-IMCI can be collected to assist with clinic supervision and to provide program managers and policy makers with a wealth of population health data.

In this paper, we report on our initial investigations into the task of automating IMCI at a dispensary in Mtwara, Tanzania. Our investigation consisted of structured interviews with the clinicians who practice IMCI, observation of patient encounters using the current paper IMCI booklet, and observation of patient encounters using our initial prototype of e-IMCI. As part of our iterative design process, this prototype was frequently reviewed and revised during this initial investigation.

Our goal is to create an electronic version of IMCI that will be used to improve care in health facilities in Tanzania. Achieving this goal requires that e-IMCI be fast to use, provide flexibility to the user and reduce deviations from the IMCI protocols. The clinicians interviewed identified speed as a primary issue. They rarely follow the recommendation of using the paper chart booklet during encounters because it is perceived as taking too long, and instead rely on their memory. There are some steps which are almost never performed, because they are seen as excessively time consuming. Finally, there are some cases in which the clinician will override IMCI intentionally based on factors not taken into account by the protocol. The findings from our initial pilot with e-IMCI are:

- **Adherence:** Using the e-IMCI prototype, clinicians performed 84.7% of investigations required by IMCI, a significant improvement over the 61% of investigations seen with the chart booklet ($p < 0.01$).
- **Flexibility:** During early pre-testing we extended e-IMCI to allow the clinicians more freedom to choose drugs and use approximate measures for certain investigations. This flexibility is necessary to allow clinicians to use common sense to interpret the protocols when necessary.
- **Speed:** Our current prototype is almost as fast as the current practice, where the book is rarely referenced. We analyzed 18 trials comparing the time by the same clinician in a traditional IMCI session to one using e-IMCI; the average for both was about 12.5 minutes.

These results suggest that e-IMCI is fast, improves adherence, and thus the quality of care, and also affords the user enough flexibility. We were further encouraged that the training time for e-IMCI was less than 20 minutes, after which clinicians were easily able to train each other. The four clinicians unanimously preferred e-IMCI to following the chart booklet, citing it as faster and easier to use. However, several sessions with e-IMCI revealed problems that must be addressed and point to the need for future usability research in this area.

## THE IMCI PROTOCOL

IMCI was developed by the World Health Organization (WHO), the United Nations Children's Fund (UNICEF) and other partners. It has been adopted by over 80 countries. IMCI is a three part approach: improved case-management, improved health systems support and improved family and community practices. Case management includes protocols, also known as medical algorithms, which indicate a simple set of investigations to perform for a child with a cough, diarrhea, fever and/or an ear ache. Figure 1 shows the IMCI flowchart of the cough protocol. The investigations for a child with a cough include counting the

[1] Tanzania recently changed the recommended treatment for malaria because of drug resistence.

breaths per minute and asking the caregiver, usually the mother but often another family member, how long the child has been coughing. The flowchart describes how to use the results of the investigations to classify the illness and determine treatment, as well as to select medications and compute dosages based on weight and age.

IMCI also guides a health worker to prompt for missing immunizations, assess a child for malnutrition, and recommend interventions for underweight children. IMCI provides advice for the caregiver including when to return (a fixed number of days, or if certain symptoms arise), how to give drugs, how to treat local infections at home, feeding recommendations and even maternal health. In cases of severe classification or danger signs, IMCI will recommend referring a child to a higher-level facility.

With IMCI, there are different rules for children from 1 week to 2 months old, and for 2 months to 5 years. Children over 5 years old are not covered by these protocols. There have been some recent additions to cover infants during their first week. There are also different rules to cover a return visit as opposed to a first visit.

## PRIOR WORK

The idea of using human-computer collaboration for automating procedural tasks, and specifically of designing user interfaces for helping human operators, has existed since the early days of human factors research. However, research has shown that this approach does not lead to positive outcomes in all cases and that "computer aiding is a multidimensional problem" [3]. Specifically, automation seems to be most helpful in cases are humans were operating under higher workloads. One example of automation using mobile devices was a system to help coordinate the movements of a large container ship and was shown to improved safety [12]. An evaluation of mobile devices used in American hospitals to write and print prescriptions found that usability problems introduced certain new errors [13].

The work described in this paper builds on a project to develop a screening algorithm for HIV patients and is currently being tested in two AIDS treatment centers in South Africa [15]. It is part of a larger effort to deliver standardized care on mobile devices at primary health facilities in low-income countries. The user interface for the HIV system, which is what the e-IMCI interface was built from, was developed by Dimagi, Inc., a health technology consultancy. The interface is based loosely on internet chat applications, and was inspired by the DiamondHelp system for collaborative home applications [20].

A related effort evaluated the use of computerized decision support in a rural area of Tamil Nadu, India [19]. The study focused on a decision support system to alleviate the burden on small clinical staff. The application offered help for non-physicians to gather information about patients, offered preventative advice, and identified treatment for simple cases, among other tasks. One of the algorithms used was the IMCI protocol. This study showed that the aid had a positive impact on both the number of patients seen as well as the quality of care received.

There is a large body of health informatics work to develop computer applications aimed at the needs of low-income regions. There have also been several telemedicine projects that attempt to connect doctors in urban areas or wealthy countries to patients in remote, rural areas (e.g., [18]). Rwanda's Treatment and Research AIDS Centre (TRAC) achieved success including remote locations to their TRACnet communications network, in part utilizing the Voxiva mobile phone network [8]. TRACnet was able to collect data from all participating clinics monthly. There have also been a number of patient record systems aimed the needs of low-income countries, including OpenMRS [17] and SmartCare [21]. In most low-income countries, health workers fill out paper forms when seeing patients, which are later typed in by data clerks. Reports are then generated to assist with clinical care and meet the reporting requirements of the governments and funders.

The feasibility of mobile applications in rural areas has been demonstrated. One compelling example is the ongoing PDA-based survey of 270,000 households in Mtwara, Tanzania, following a smaller baseline study [22].

There has also been work discussing the importance of adapting HCI design methods, including participatory and user centered design, from the developed world to working with rural communities [14]. This work serves as a guide to inform design in a new environment.

Clinical decision support systems have also been deployed in wealthy nations in specific areas, often in an attempt to improve on the judgment of well-trained doctors. A 1998 survey of these support systems showed that quality of care was improved in 66% of the studies performed [10]. These systems were predominantly deployed in the United States for use in teaching hospitals and academic environments. The success of these systems is encouraging for our work assisting medical professionals in the low-income regions, who receive a lower level of education and deal with a larger patient load.

There has also been work on designing representation languages for decision protocols. One notable effort is the the GuideLine Interchange Format (GLIF) [16]. GLIF is a second generation protocol specification format, created by integrating the experience from the development of four different earlier guideline representations. GLIF has achieved a large level of success in the representation of diverse medical guidelines [16]. Columbia University is currently integrating GLIF with an existing computer-based physician order entry (CPOE) system to enhance the system's decision support capabilities [5]. While we have hard-coded the IMCI protocols into e-IMCI, we plan to use GLIF or some other standard for generically representing medical protocols.

The artificial intelligence community has done work to provide medical advice using machine learning. These 'expert systems' are generally designed to accept a specific set of information and make rule-based assessments in a narrow range of results. Early examples of expert systems include Mycin, a 1970's Stanford system for recommending a proper antibiotic and dosage for blood-borne infections [6]. Other efforts have investigated the use of probabilistic reasoning to approximate expert human medical assessment. For example, the PATHFINDER system for pathological diagnosis performed probabilistic determinations based on measurements of features seen in microscopic analysis. This system performed at the level of an expert pathologist [9].

Both the work on expert medical systems and probabilistic medical systems take a different approach to automating health care than the work presented here. We are relying on the designers of the IMCI protocols and are focused on the human-computer interaction issues of how to build a tool that can improve adherence to established protocols, and thus increase the standard of care.

Finally, it has been shown that computer systems for training IMCI were 23-29% less expensive and as effective as standard training methods [13]. In future work, we plan to explore the potential for e-IMCI to reduce the need for training or be used as a training tool.

## THE e-IMCI PROTOTYPE

The e-IMCI system was developed by adapting the HIV screening system mentioned above. Figure 2 contains an example of e-IMCI for numeric data entry and another for a simple yes/no question. The current question is displayed at the bottom of the screen along with the possible answers. When a question is answered, it is scrolled upwards; an abbreviated version of the question and the selected answer appear above the new question. Of the entire IMCI protocol, e-IMCI currently covers:

- First visits (not follow ups)
- Children between 2 months and 5 years old (not 0-2 months)
- Children without any of the IMCI danger signs
- Cough, diarrhea, fever and ear problems (not immunizations, malnutrition or maternal health)

Even with these limitations, e-IMCI covered most cases we observed. The system starts by confirming that the patient consents to the clinician using the PDA. The second question is a multi-select widget that prompts for the 4 danger signs: vomiting, convulsions, trouble drinking and lethargic/unconscious. Currently, if any danger sign is selected, e-IMCI displays a message telling the clinician to use the chart booklet. This was done to ensure that the study would not jeopardize the safety of ill children while we were testing e-IMCI.

The third question asks about the major symptoms that the patient is presenting with, such as: cough, diarrhea, fever


**Figure 2: The e-IMCI interface.**

and ear problems. This is also a multi-select, allowing the clinician to record all major symptoms at one time. After the assessment questions are asked, the system indicates the classification, e.g. "The child should be treated for pneumonia." If IMCI indicates any medications, e-IMCI allows the operator to choose from the available drugs, and the form of medicine (e.g., adult tablets, child tablets, syrup), and computes the correct dosage based on the child's weight and age. The system then presents advice to convey to the child's caregiver, e.g. return immediately if any blood develops in the child's stool.

Because the clinicians are required keep records in English, they requested e-IMCI be in English rather than Tanzania's national language, Swahili, in order to keep the vocabulary consistent. However, as discussed below, we plan to translate the system to Swahili, which we expect to improve performance and usability.

## RESEARCH FOCUS AND METHODS

The long term goal of this project is to attempt to improve the care of children by deploying standardized care on mobile devices. There are several common questions raised about such an approach:

1. Will it be cost effective and sustainable?
2. Will health workers continue to use such a system for very long? (They tend not to use the paper charts long after training).
3. Will the project fail because too many devices will be lost, stolen, or broken?
4. Will there be sufficient electricity to charge devices?
5. Will health workers be able to use it given their limited exposure to computers?
6. Will health workers or patients dislike it?

We add three questions that are more specific to the work described in this paper:

7. Will e-IMCI really reduce or eliminate errors in following IMCI?
8. Will e-IMCI introduce new kinds of errors into care?
9. What are the interesting HCI / usability issues to address to improve e-IMCI?

Our investigation focused on questions 5-9, though we will briefly discuss questions 1-4. While an extensive cost-benefit analysis is outside the scope of this paper, there is evidence that using IMCI properly reduces the cost of medical treatment in Tanzania [1]. If we can improve treatment further with e-IMCI, or reduce supervision costs, we expect this to compensate for the cost of the PDAs. However, more detailed analysis is required to make any substantial claims about the cost-benefit.

We hypothesize that e-IMCI will continue to be used because of the benefit of navigating through the protocol and the consequence of better supervision. However, a longitudinal study is required to assess long-term use. We plan such a study after further refinement of e-IMCI.

We can find encouragement on the issues of theft, loss, and infrastructure from past projects using PDAs in low-income regions. For example, our colleagues in Tanzania recently conducted large-scale data collection from both health facilities and home visits in rural Tanzania using PDAs. From their experience, it seemed it may be preferable to use PDAs rather than mobile phones because they are less desirable and thus less likely to disappear [Schellenberg, personal communication]. Over a seven week period in 2004, IHRDC was able to capture data from 21,600 households using 104 PDAs. During the entire study, no PDAs were lost or stolen and only one was broken, though no data was lost [21]. A solar charger was used to keep the device charged when grid power was not available.

### Field Test

We field tested our prototype at a dispensary in Mtwara, Tanzania staffed by five clinical officers, who had all been previously trained in the use of IMCI. Because of a lack of roads and infrastructure, the area is relatively underdeveloped. The majority of the population belongs to the Makonde tribe and work as farmers or fishermen. Imported goods are expensive due to the cost of transportation.

### Methodology

First, we demonstrated the software for all five of the clinicians in the dispensary. We then ran approximately ten informal pre-trial sessions with two clinicians in which we gathered feedback and made major changes to the system.

For the actual study, we first conducted interviews with the five clinicians in order to understand their level of experience with computing devices, experience with IMCI and preconceptions about using the PDA to administer the protocol.

**Figure 3: Clinician using e-IMCI prototype with a patient.**

Next, we observed each clinician delivering care as s/he would normally to gather data on the adherence to the IMCI protocol, the time it takes to deliver IMCI, and current clinical practices. For consistency, we gathered data only on first visits for children 2-months to five years old without danger signs, i.e., those who would be covered by our current implementation of e-IMCI. We were able to observe 5 sessions for four of the clinicians and 4 sessions for clinician 5, for a total of 24 sessions. We refer to these sessions as paper-based trials or current practice in the text, but 14 of the 24 did not involve the use of the chart booklet. All 24 observed sessions are included in our analysis.

After these trials, we re-introduced the software, informally training one clinician by having her walk through an example classification and treatment. At this point, the clinician went on to train the others in a similar manner while the researchers observed. From here, we observed a series of trials in which the clinician used e-IMCI to classify and treat child illnesses under the observation of a clinical officer who helped both to assess the system and ensure that safe care was given. At any point, the practicing clinician, the observing clinician, or the child's caregiver could request that the system be put aside for the remainder of the session. We were only able to test the system with four of the five original clinicians, as during our study clinician 2 changed jobs. We observed 31 e-IMCI sessions, but 2 children had danger signs and the software crashed one other occasion. This left us with 28 samples. Finally, we conducted a semi-structured exit interview with each of the four remaining clinicians to assess their perception of e-IMCI.

During the pre-study, we changed our system frequently based on user feedback and our observations. Only minor changes were made during the actual study.

We measured protocol adherence for both the paper chart and e-IMCI by instructing the observing clinician to fill out a paper form with a checkbox for each of the danger signs, clinical investigations, and advice elements. We also

recorded whether the clinician referred to the chart booklet and timed each visit to the nearest minute.

## RAPID PROTOTYPING OF E-IMCI

Several of our observations reveal the need for e-IMCI to provide flexibility to the operator.

### Correct Application of IMCI led to Incorrect Treatment

There were two cases where the clinician deviated from IMCI to provide what they thought, and the observing clinician agreed, was better treatment. This is not surprising because no set of rigid protocols will be comprehensive or ideal in all cases, and indeed IMCI is bounded by how complex a paper protocol can be without being too difficult to learn or follow. Both cases point to the need for flexibility in e-IMCI however, since no such system will be able to account for all situations that arise.

*Case 1: Cough syrup (pre-study)*

The child presented with a cough on her first visit to the clinic. According to the signs and symptoms, e-IMCI classified the child as having a cough or cold with no pneumonia. However, the caregiver reported she had given the child cough syrup and the cough had persisted. Because of this information, the clinician decided to override the IMCI classification and treat for pneumonia.

We changed the software to allow the clinician to agree or disagree with the classification. We plan to add support for changing the classification explicitly so that e-IMCI can suggest the correct treatment for the new classification.

*Case 2: Ear problem (during study)*

A young girl was brought to the clinic complaining of a problem with her ear. After performing all of the investigations required by IMCI in the case of an ear problem, e-IMCI classified the child as having no ear problem. The clinician agreed with the classification, but treated for *otitis externa*, which is not a classification that IMCI would arrive at.

The IMCI protocols are designed for simplicity because they are to be used in primary care settings with limited resources and by clinicians with limited training. The introduction of an electronic device means we can support a larger number of more complex protocols. This points towards future research for medical protocol researchers, but also suggests allowing the manual entry of a classification in the case that the child should be treated for something that the protocol does not support.

### Local Preference

We discovered a few cases where IMCI did not exactly match the preferences and capabilities of the dispensary.

*Case 3: Pneumonia Antibiotic (pre-study)*

A child presented with signs of pneumonia. The software correctly classified this case and asked the clinician which form of cotrimxazole should be used. However, the PDA was put down and a different antibiotic was given.

According to IMCI, the first-line antibiotic for pneumonia is cotrimoxazole. However, the clinician preferred to give an injectable antibiotic. We changed e-IMCI to present a choice of antibiotics and the ability to prescribe 'other'.

*Case 4: Danger signs (during study)*

The clinician did not use e-IMCI because the child had been convulsing recently (a danger sign). IMCI was followed and the child was classified with very severe febrile disease or severe malaria. Instead of referring to the larger Ligual hospital, the mother was instructed to purchase quinine to be administered at the dispensary because the resources to give the drug were available locally.

*Case 5: Lab use (during study)*

The dispensary was in the process of transitioning into a health clinic, and therefore had a lab available. The clinicians expressed that patients showing sign of fever should be referred to the lab to be tested for malaria rather than prescribed anti-malaria medication immediately. The national standard of IMCI is designed for the least common denominator—a facility without a laboratory—and recommends anti-malaria medication for almost any patient with a fever. This is a case where e-IMCI could easily be tailored to the context in which it is being applied.

*Case 6: Nose flaring (during study)*

During the observed paper-based sessions, the clinicians would check for nose flaring in a child with a cough as a sign of severe pneumonia. We added this to e-IMCI, but incorrectly thought that any case where the child exhibited nose flaring should be classified as severe pneumonia. We received conflicting information about how nose flaring fit into the protocols, and eventually omitted it from e-IMCI. This highlights the need for clear standards.

## RESULTS

It quickly became clear that the chart booklet is infrequently used during patient encounters. Of 24 paper-based sessions we observed, only 10 referred to the chart booklet. Our understanding is that this is true in most dispensaries because the chart booklet takes too long to use and clinicians quickly become familiar with the IMCI process. Thus, in this section we compare e-IMCI to the current practice, which is primarily the use of IMCI from memory with occasional reference to the chart booklet. Our design challenge is to improve adherence without being slower than current practice.

### Adherence

During the pre-survey, the clinicians were asked how they thought e-IMCI might help. Two of the five interviewed stated that they thought the device would remind them of things they would have otherwise forgotten. As one

clinician put it, "sometimes since I have experience [with IMCI] I will skip things, but with the PDA I can't skip."

Skipping investigations can lead to incorrect drug dosing or treatments. For example, if the clinician does not check for a stiff neck in a child with a fever, s/he may incorrectly classify the case as *uncomplicated malaria rather than very severe febrile disease or severe malaria* .

For each session, the observing clinician recorded which of a total of 23 investigations were performed. Of these, 20 were asked more often with e-IMCI, 2 had 100% adherence both with and without e-IMCI, and only the temperature investigation showed signs of lower adherence with the e-IMCI software. We attribute this to an inconsistency in data collection: sometimes the temperature was marked as taken only when a thermometer was used, while during other cases it was also marked if the clinician used physical touch to determine the presence of a fever. From the 24 paper-based trials there were 299 IMCI investigations that should have been performed. Of these, only 183 (61%) were actually observed. For the 28 e-IMCI based trials there were 304 out of 359 (84.7%) investigations observed, showing better protocol adherence with the e-IMCI software ($p < 0.01$).

We also ran a second analysis on data elements that were most reliable. We removed the 3 IMCI-indicated advice elements; we thought it best to view these separately, and discuss them in the next section. Furthermore, it was difficult to observe whether certain investigations are performed or not. For example, a clinician might be able to tell if a child has sunken eyes without obviously checking the child's eyes. While we asked the clinicians to say what they were doing, this seemed more likely to happen in the e-IMCI sessions when they were explicitly prompted about the investigation. We removed checks for stridor, stiff neck, sunken eyes, ear discharge and ear pus on these grounds. Finally, we removed taking the temperature and checking for respiratory rate because there was a lack of clarity in our data capture as to whether or not these investigations should be counted if the clinician felt the child for temperature or judged whether or not the child had fast or slow breathing without counting breaths. Future data capture will address these inconsistencies.

This left 104 of 160 (65%) for the paper-based trials and 170 of 184 (92%) for the e-IMCI trials. The one-tail z-test again determined that the proportions were statistically significant ($p < 0.01$).

Table 1 shows results for five individual investigations with the corresponding p-values. They were selected because of our confidence in the data quality for these particular investigations and because they include each category covered by IMCI: danger signs, cough, diarrhea, fever and ear problems. In all cases, e-IMCI was observed to have significantly higher adherence, though not all investigations individually are considered statistically significant.

| Investigation | Current practice adherence | e-IMCI adherence | p-value |
|---|---|---|---|
| Vomiting | 66.7% (n=24) | 85.7% (n=28) | † |
| Chest indrawing | 75% (n=20) | 94.4% (n=18) | † |
| Blood in stool | 71.4% (n=7) | 100% (n=3) | † |
| Measles in the last 3 months | 55.6% (n=9) | 95.2% (n=21) | < 0.05 |
| Tender ear | 0% (n=1) | 100% (n=5) | † |
| All | 61% (n=299) | 84.7% (n=359) | < 0.01 |

**Table 1: Selected adherence results († p-value > 0.05)**

We noted a distinction between steps that are deliberately skipped and ones that are forgotten. While the clinicians occasionally forget a step and simply need to be reminded of it, we identified three questions that the majority of the clinicians typically skipped intentionally because of the amount of time they took: taking the child's temperature, required for every patient; counting the number of breaths per minute, required for a child with a cough; and offering the child fluid to see how eagerly he drinks, required in the case of diarrhea. Instead, the clinicians use their judgment to approximate the answer or ask the caregiver. It will be necessary to find a proper balance between usability and protocol adherence to ensure that the best care is delivered and the protocols are used as intended.

### Advice to the care taker

Early in our investigation, we observed that clinicians often did not provide the IMCI-recommended advice or counseling to the mother. We were told that in Tanzania it is not uncommon for a patient to go to a health facility, see a clinician, receive medication and take the medication without ever knowing what was wrong in the first place. The problem is twofold - doctors and clinicians do not give out this information readily nor do patients ask for it.

As shown in Table 2, on average the recommended advice was given much more often with e-IMCI than in the non-PDA sessions ($p < 0.01$). Clinician 2 was omitted because s/he was unable to perform e-IMCI trails prior to changing jobs. The table shows that with the exception of clinical officer 5, all were more likely to give advice when using e-IMCI than without, though only the results for clinician 1 and 3 are statistically significant ($p < 0.01$ and $p < 0.05$).

### Efficiency

At the dispensary, the caregivers sit outside the visit room on benches. The large number of patients waiting adds pressure to the clinician to make visits as quick as possible. The long term use of e-IMCI likely depends on the time it

| Clinical Officer | Current practice advice adherence | e-IMCI advice adherence | p-value |
|---|---|---|---|
| 1 | 20% (n=15) | 76.9% (n=39) | < 0.01 |
| 3 | 26.7% (n=15) | 66.7% (n=18) | < 0.05 |
| 4 | 80% (n=15) | 100% (n=12) | † |
| 5 | 100% (n=12) | 73.3% (n=15) | † |
| All | 56.9% (n=72) | 77.4% (n=84) | < 0.01 |

**Table 2: Adherence results for advising caregiver when to return for a follow-up visit († p-value > 0.05)**

adds to a patient visit. During the exit interview, one clinician explained that the chart booklet is not followed because it is slow. She said that e-IMCI was much faster because there were no pages to turn and no thinking was required to determine the next question. She did admit that using experience was the fastest, but cited forgetting questions (unintentional deviation) as a major drawback.

We recorded visit lengths to gather quantitative data. However, there was rarely a case where the clinician was not interrupted by other staff coming in for supplies or advice. Table 3 has a summary of visit length for e-IMCI compared with visit length for non-PDA trials. Note that for the majority of paper-based trials patients were treated from experience without referencing the chart booklet.

We measured the 95% confidence interval of the difference between the mean of the paper-based visit lengths and the e-IMCI visit lengths with an unpaired t-test for each of the clinicians individually. In Table 3, the negative number represents how much slower e-IMCI trials would be in the worst case, within the 95% confidence range. The first e-IMCI sample for clinician 5 was removed as an outlier from all calculations. The visit lasted for 33 minutes, over one and a half standard deviations (9) away from the mean for that clinician. The majority of the time was spent with the clinician carefully reading and reviewing his work as he became used to the e-IMCI interface and device. All subsequent visits lasted less than 20 minutes.

To measure the statistical significance of the average times across all clinicians, we ran a paired t-test on 18 of the trials. We matched as many as possible and ignored any excess. The difference between the times of traditional IMCI and e-IMCI shows that e-IMCI is from 2.4 minutes faster to 2.4 minutes slower than traditional IMCI ($p < 0.05$). While this means that e-IMCI may be 25% slower than IMCI, this seems a tolerable increase; and we believe we can improve upon these times in future work.

During sessions with e-IMCI it became clear that the visits would have been faster if we had translated the text into Swahili, as reading English was often a slow process.

| Clinical officer | Average length of current practice visit (minutes) | Average length of e-IMCI visit (minutes) | Mean of e-IMCI minus current practice ($p < 0.05$) |
|---|---|---|---|
| 1 | 16 (n=5) | 13 (n=13) | -2.1 to 7.9† |
| 3 | 6 (n=5) | 8 (n=6) | -5.5 to 1.0† |
| 4 | 7 (n=5) | 9 (n=4) | -5.7 to 4.7† |
| 5 | 19 (n=4) | 14 (n=4) | -2.1 to 13.1 † |
| Total | 10 (n=24) | 11 (n=27) | -2.4 to 2.4 ‡ |

**Table 3: Summary of paper and e-IMCI times. († unpaired t-test, ‡ paired t-test of 18 trials)**

### Limitations of e-IMCI

We observed a variety of limitations of e-IMCI which we intend to address in future work.

#### *Question grouping*

We found that during paper-based sessions the clinicians preferred to ask all questions of the caregiver before beginning any physical investigations of the child. We have yet to test regrouping questions in this manner, but it is planned for future experiments. We also found that several investigations were often performed concurrently. For example, in the case of a cough, the clinician would check for chest indrawing, stridor and nose flaring all at the same time. To address this and to speed up the PDA-based sessions, we plan to experiment with combining questions onto a single screen. We belive these changes could substantially increase the speed of e-IMCI.

#### *Threshold problem*

The introduction of the PDA reduces the amount of human judgment used in the treatment of the patient. In IMCI and e-IMCI, there are cases where the patient is on the border of a threshold between two different classifications. In such cases, because e-IMCI effectively hides the protocol from the clinician, an incorrect treatment may be given.

For example, while using e-IMCI with a patient who presented with a cough, the clinician measured the number of breaths per minute as instructed by the PDA. The result was 36, just below the threshold for pneumonia, which for the patient was 40 breaths per minute. Since the clinician was familiar with IMCI she was aware of this. To further complicate the case, the child was exhibiting mild signs of chest indrawing—which lead to a classification of severe pneumonia in the IMCI protocol. In this case, the clinician put down the PDA and made an objective assessment. A less experienced clinician could have proceeded without knowledge of the threshold between different classifications. We call this the *threshold problem*.

We have hypothesized various solutions to this problem, but have yet to test them. Changing the background color of the screen based on proximity to the threshold, using a slider widget to enter numeric data, or explicitly listing the thresholds while asking for numeric data are all viable options that we are planning to field test in the near future.

### Observed Benefits of e-IMCI

There were several observed benefits of e-IMCI. Our data suggests that training was surprisingly quick and all of the clinicians had a positive reaction to the system.

#### *e-IMCI training*

Of the five clinical officers, none had any experience with computers or PDAs. Three owned mobile phones and the other two had owned a mobile phone in the past. We were initially concerned about the lack of computer skills, but it proved not to be a problem.

Training the clinicians to use the e-IMCI software was easier than expected. Instead of conducting training sessions with all five[2] clinical officers individually, we demonstrated the system to one clinical officer who took it upon herself to show it to the rest. Our initial demonstration took only ten minutes. Since the clinical officers were all familiar with IMCI, the questions and process were familiar and intuitive. During their use of e-IMCI, the clinicians made extremely valuable suggestions about how to improve the interface and question flow.

One of the clinicians was also an IMCI instructor. In the exit interview, he told us that his entire two week course is spent teaching the students—who all have a medical background—how to use the chart booklet. They do numerous case studies with the students to ensure that they can properly classify patients. In his opinion, if the PDA was used, training time could be cut significantly. Even with no previous PDA experience he felt that the training would be much shorter than two weeks, making it less expensive to train new health workers. He felt that those who had already taken the IMCI course could be trained in 2 days or less to use the PDA. We plan to explore how much training is required for medical personnel, both familiar and unfamiliar with IMCI, in future work.

#### *Clinician reaction*

After explaining the role of the PDA and giving a short demonstration, we asked the clinicians what they expected to like the most and the least about the PDA. The clinicians unanimously said there was nothing to dislike about the PDA if it contained all of the information in the chart-book. They requested extensions to the system to support the complete IMCI protocols (malnutrition, immunizations etc…). In general, users liked the interface, saying it was easy to learn.

After using e-IMCI, one clinician asked if it would be possible to use the PDA for the CTC (Care Treatment Clinic), which is the HIV treatment clinic standard in Tanzania. We explained that at this time the device was not capable, but it was something we hoped to do in the future.

In the final interview, all four of the clinicians said they would prefer to use the PDA device and would use it every day. They said that the e-IMCI software was faster than the book and asked us to return to their clinic when we are ready to continue the next phase of our research.

## CONCLUSION

This work represents our first steps towards the goal of creating an electronic version of IMCI that will be used and will improve care in health facilities in Tanzania. We have partially answered each of the research questions 5-9 set out earlier in this paper and the initial feedback from clinicians has been positive. Our work also suggests that health workers will be able to operate e-IMCI, which is not surprising given the rapid increase in mobile phone use in Tanzania.

Additionally, we have presented evidence that e-IMCI can reduce errors like unintentional deviations from IMCI, leading to improved care. While more testing is required to prove conclusively that the current e-IMCI prototype will do so, we have seen substantial evidence that there is some room for improvement in current practice and that e-IMCI has the potential to address it. However, we have also identified several areas that require future HCI research including problems introduced by e-IMCI, such as the threshold problem and ensuring adequate functionality, as well as addressing issues such as grouping and reordering of questions. We plan to explore the trade-offs between having a system which is fast, flexible, and does not ask the operator to perform unnecessary investigations while strongly encouraging adherence to the IMCI protocol.

Our next steps will involve more focused studies to complete and extend the prototype, but many important questions about e-IMCI's effect on health outcomes can only be answered through a longitudinal study. We are in the process of acquiring funding to do such a study.

We also need to understand what barriers there are to continued use of e-IMCI after many months, but there are many opportunities to encourage continued use. For example, assisting the clinicians with monthly reporting requirements, or perhaps introducing a label printer to reduce the amount of writing they need to do on the patients' personal records would save time and reduce the amount of tedious work. Another important area of research is whether we can develop an abbreviated training course for the use of e-IMCI for health workers as yet untrained in IMCI. We will attempt to adapt the electronic training course mentioned in prior work to these ends.

There is much potential for computer science in general, and HCI in particular, to address some of intolerable

[2] Initial training was performed before clinician 2 left.

inequities facing the extremely poor. We sincerely hope that this work motivates others in the community to explore the variety of challenges facing low-income countries around the world.


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