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Health workers' perspectives of a mobile health tool to improve diagnosis and management of pediatric acute respiratory illnesses in Uganda: A qualitative study

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Abstract

Objectives: Mobile health tools have potential to improve the diagnosis and management of acute lower respiratory illnesses (ALRI), a leading cause of pediatric mortality worldwide. The objectives were to evaluate health workers' perceptions of acceptability, usability, and feasibility of ALRITE, a novel mobile health tool to help frontline health workers diagnose, treat and provide education about ALRI in children <5 years.

Design: A qualitative study including informal semi-structured interviews with health facility administrators and focus groups and qualitative usability evaluations with primary care health workers.

Setting: Two federally funded Ugandan primary care health facilities, one peri-urban and one rural.

Participants: We enrolled 3 health administrators and 28 health workers (clinical officers and nurses).

Intervention: The ALRITE smartphone application was developed to help frontline health workers adhere to ALRI guidelines and differentiate wheezing illnesses from pneumonia in children under 5 years of age. ALRITE contains a simple decision tree, a partially automated respiratory rate counter, educational videos, and an adapted respiratory assessment score to determine bronchodilator responsiveness.

Results: Themes impacting the potential implementation of ALRITE were organized using individual-level, clinic-level, and health-system level determinants. Individual-level determinants were acceptability and perceived benefit, usability, provider needs, and provider-patient relationship. Clinic-level determinants were limited resources and integration within the health center. Systems-level determinants included medication shortages and stakeholder engagement.

Conclusions: Incorporation of these themes will ready ALRITE for field testing. Early engagement of end-users provides insights critical to the development of tailored mHealth decision support tools.

Strengths and limitations of this study

- Health workers reported high acceptability and usability of our novel mobile health tool, while also providing critical feedback for improved usability and adaptation to their clinical setting.
- Health worker and health administrators provided a rich understanding of the health setting and potential systems-based and individual level challenges to implementation.
- This study was limited by perspectives at two health centers, which may not reflect regional differences in resource availability, staffing, and health workers' perceptions.
- Health worker perceptions were obtained without experience using ALRITE in clinical practice, which will be a focus of future work.
- Our results support the continued development of tailored mHealth tools for decision support in LMICs based on high user acceptability and usability.

Keywords: Community child Health, international health services, paediatric thoracic medicine, respiratory infections, qualitative research, public health

INTRODUCTION

Acute lower respiratory illnesses (ALRI) remain a leading cause of mortality in children under 5, responsible for 15% of all deaths in this age range.[1 2] Over 800,000 young children worldwide die of ALRI each year; 500,000 of these deaths occur in sub-Saharan Africa.[1-5] In Uganda, ALRI is responsible for 11% deaths in children under 5.[5 6] ALRI encompass multiple disease processes that include bacterial pneumonia, viral pneumonia, and wheezing illnesses. Differentiating between these diseases and choosing the appropriate treatment plan is challenging, especially where skilled personnel and diagnostic tools are lacking. The World Health Organization (WHO) Integrated Management of Childhood Illnesses (IMCI) provides guidelines for ALRI diagnosis and management, with emphasis on pneumonia and treatment with antibiotics. The IMCI was updated in 2014 to include assessment of wheezing and treatment with inhaled bronchodilators,[7] but wheezing illness remains underdiagnosed and undertreated in low- and middle-income countries (LMICs).[8,9]

Mobile phone use recently surpassed two-thirds of the global population and over 70% in Uganda[10], offering opportunities for digital health tools to enhance adherence to guidelines and build capacity through clinician education.[11-16] Importantly, small pilot studies of mHealth tools based on WHO IMCI ALRI guidelines demonstrated promising preliminary results but have not addressed wheezing illness.[17-20] To promote responsible, sustainable, and high impact mHealth interventions in LMICs, the WHO recently released digital health guidelines recommending high quality research in fields of decision support and education.[21]

We developed the Acute Lower Respiratory Illness Treatment and Evaluation (ALRITE) mHealth application as a decision support tool to aid frontline health workers to improve diagnosis and treatment of ALRI in children under 5 years of age, with a particular focus on distinguishing wheezing illness from pneumonia. In order to address potential challenges with

widespread ALRITE use, this study sought to understand determinants of successful ALRITE implementation from the end users' perspective. The objective of this study was to evaluate health workers' perceptions of feasibility, usability, and acceptability of the ALRITE mHealth tool in two Ugandan primary care health centers. This user-centered, formative approach will inform further development of a locally relevant decision support tool to improve the diagnosis and treatment of ALRI in Ugandan health centers.

METHODS

Study design

This study uses a human-centered, or participatory, approach to examine frontline health workers' perceptions of ALRITE and its impact on their workflows and patient care. We developed an initial prototype of ALRITE and used it as a technology probe to gather insights about its feasibility, usability, and acceptability.[22] We used a qualitative approach consisting of informal semi-structured interviews with health facility administrators and focus groups with primary care health workers (clinical officers and nurses). We also performed qualitative usability evaluations, in which we guided users through 2-3 clinical scenarios with limited prompting to obtain information on user agility (moving through the app screens), user feedback, and errors made during the scenarios.

Study sites

Both study sites were federally funded Health Center IV in Jinja district, Uganda and offer free healthcare. The peri-urban site is located 15 minutes driving from the city center of Jinja, the second largest city in Uganda, and the rural site is located 45-60 minutes driving from Jinja. Both sites have inpatient and outpatient facilities and an operating theater for obstetrics and urgent surgical cases.

The health care delivery system in Uganda has 6 levels that build on the previous level: 1) Health Center II provides basic outpatient care; 2) Health Center III has maternity services; 3) Health Center IV has primary care, basic inpatient facilities and emergency obstetric care; 4) District Hospitals have general surgery, dental services, and diagnostic services (i.e. chest radiography and laboratory); 5) Regional Referral Hospitals have specialized care; 6) National Referral Hospital has additional specialized and sub-specialized services.

The two specific Health Center IV were selected for this study based on prior research indicating that 1) adherence to IMCI was low, 2) consultations were performed by health workers with limited training, 3) antibiotics were over-prescribed, and 4) inhaled bronchodilators for wheezing illness were not prescribed.[9]

Participants

We recruited at least 1 health administrator for semi-structured interviews from each study site. Health administrators were clinicians (medical doctors or clinical officers) who serve a director role in leadership and staff supervision at an individual health center, termed locally as “health facility in-charges”. Eligible participants for focus groups were health workers (clinical officers or nurses) who had been working at the study site for at least 6 months and were responsible for outpatient care of children. Clinical officers complete a three-year diploma course in clinical medicine. Nurses in these health centers primarily act as clinicians due to staff shortages and task shifting. The study team employed in-person information sessions for recruitment using convenience sampling. All participants provided a written informed consent in English for their participation.

ALRITE mHealth tool

Based on a previous mHealth tool, mPneumonia[17 18], the ALRITE mHealth application was developed for smartphones to help frontline health workers adhere to IMCI guidelines and differentiate wheezing illnesses from pneumonia in children under 5 years of age. ALRITE contains a simple decision tree, a partially automated respiratory rate counter, educational videos, and an adapted respiratory assessment score to determine bronchodilator responsiveness (Figure 1). The algorithm walks the user through basic demographics, IMCI danger signs, medical history, physical exam, and bronchodilator assessment (if appropriate). The final diagnoses include severe disease, pneumonia, wheezing illness, and upper respiratory illness. The app is 27 MB and was downloaded on supplied Android smartphones for study use.

Data collection

Focus groups and interviews were performed primarily in English using interview/focus group guides and clinical scenarios for usability evaluations (Supplementary information). Ugandan research assistants did provide clarifications and some probing in the local language; some participant responses were given in the local language and translated to English for the study notes. All interviews and focus groups were digitally recorded, deidentified, and transcribed into English by IN, who is fluent in English and the local language. Transcriptions were reviewed by IN and LEE for content and cultural accuracy. Members of the study team (LEE, IN, MR, SAF) took notes during usability evaluations, focus groups, and interviews to augment and clarify the transcribed notes.

Study team

This was an international collaboration, including experts in public health, pulmonology/asthma, information and communication technology for development, human-computer interaction, and community-based interventions. Research assistants BN and ZN from Uganda experienced in qualitative interviewing and fluent in the local language led focus groups and interviews with the

guidance of LEE, a content expert in the ALRITE app with previous qualitative experience in technology implementation. SAF provided qualitative expertise in design, data collection, and analysis. RN provided local expertise in health systems, qualitative design and interview guides, and pediatrics. IN provided local research coordination and knowledge of the health system. Pediatric expertise was provided by RN and JS with additional pediatric pulmonology expertise by MR and LEE. ALRITE app design and development was performed by AK, AV, and RA, with additional expertise in usability evaluations and human-centered design by AV.

Analysis

We analyzed our detailed notes and transcripts using an inductive thematic approach, whereby the researchers LEE, SAF, and IN examined the data to identify common themes for each of the research questions. During the analysis, the team documented outlier or dissenting perspectives in order to provide a more complete picture of participant responses to ALRITE. First, LEE and SAF read through each of the transcripts and set of notes and then we developed a provisional framework based on primary research questions. LEE, SAF, MR, IN, BN, and ZN held team meetings following each day of data collection to compile notes, review emerging themes, and refine the coding framework. Codes were aggregated into major themes and subthemes without the use of coding software. Additional meetings with the research team allowed for further refinement of themes and subthemes. Transcripts were reread to ensure that preliminary results represented the majority of user feedback. The quotes were chosen to confirm and highlight themes and introduce diverging viewpoints not previously captured. The Standards for Reporting Qualitative Research (SRQR) were used to guide reporting.[23]

Ethics

The study was approved by the Mulago Hospital Research and Ethics Committee and Uganda National Council for Science and Technology (HS2692). The study was reviewed and received exempt status from the University of Washington (STUDY0007895).

Patient and Public involvement

While not involved in the design, conduct, or reporting, study participants are involved in ultimate design and implementation of the intervention and are included in the dissemination plan, along with district- and national-level health system members and patient caregivers.

RESULTS

Participant & setting characteristics

In January 2020, we enrolled 28 healthcare provider participants across 2 health centers in Uganda. Key stakeholders, including 3 health administrators (HA), took part in individual in-depth interviews, while 5 clinical officers and 20 nurses (HW) took part in 3 focus groups (Table 1).

Table 1. Focus group participant characteristics

	Rural Site (n=12)	Peri-urban Site (n=13)
Role		
Clinical officer	2	3
Nurse	10	10
Female	9	10
Age		
<30 years	5	5
30-40 years	5	6
>40 years	2	2
Experience in health care, years		
< 5	2	3
5-10	8	4
> 10	2	6

We identified several themes impacting the development and implementation of ALRITE in Ugandan health centers from the perspective of health administrators and frontline health workers. Themes were organized by a social ecological model of determinants: individual, clinic, and health system (Figure 2). Individual-level determinants were acceptability and perceived benefit, usability, provider needs, and provider-patient relationship. Clinic-level determinants were limited resources, integration within the health center. Systems-level determinants included medication shortages and stakeholder engagement. Each theme is presented below in greater detail and with direct quotes that typify respondent comments.

Individual-level

Acceptability & perceived benefit of ALRITE

All health workers indicated they would like to have ALRITE available to use in their healthcare setting. Health workers also reported that they appreciated that ALRITE reminded them of important medical questions to ask and key components of the physical exam.

> "It helps us to remember the clear assessment of these children because at times you are rushing and forget to assess something. You go with what you see quickly, but the app gives you the procedure to follow. It also helps in giving the right doses." HW-002-FG2

They responded positively to the integrated respiratory rate counter. Health workers' eagerness to learn was apparent during focus groups and interviews. Indeed, many health workers reported the educational videos were one of their favorite features of ALRITE. In addition to data gathering, health workers liked the information management capabilities, including medication dosing, which is generally age- or weight-based for children.

> "The part of the app that I like mainly are the videos. It is good because it helps diagnosing and guides through the right treatment hence saving patient time." HA-001

> "[The respiratory rate counter] is convenient because you may not have a watch." HW-007-FG3.

It is important to acknowledge the novelty of ALRITE as a mHealth app technology likely contributed to high acceptability by health workers as well.

> "[Providers] usually like new technology, I think they will be excited to use it and therefore they are likely to download [the app]. In addition, people prefer digital information than opening and reading what is in the [IMCI] book." HA-003

Respondents had ideas for improving acceptability, appropriateness, and potential benefit of ALRITE. Health workers asked for additional automated or semi-automated smartphone tools, such as pulse oximetry or digital auscultation to be integrated into ALRITE. Multiple health workers commented on the potential for storage of clinical information. One health worker wanted to use it as a personal quality control device to review his previous diagnoses and treatment plans. A few wanted the app expanded to other disease processes and age groups. Some health workers suggested incorporating additional educational components targeted to patients and families. One health worker suggested incorporating risk stratification for children with chronic disease and environmental risk factors (i.e. smoke exposure, crowded housing) in order to focus on prevention.

> "[In the app], we are missing [a question on] the type of fuel used at home to cook and source of light. Some produce a lot of smoke. [By offering recommendations, families] can change the way of cooking, hence reducing exposures. This could help in prevention [of respiratory diseases]. We therefore can make a recommendation and follow up in about 6 months." HW-005-FG3

ALRITE usability

We defined usability as "the design factors that affect the user experience of operating the application's device and navigating the application for its intended purpose."[18] ALRITE features that contributed to a positive user experience included overall design, simplicity, flow, and clarity of diagnosis. Generally, health workers thought the app was easy to follow and would be quick to get to diagnosis.

> "It saves time. You diagnose very fast and you are able to know the treatment to give so it improves on the appropriate management of patients." HW-001-FG1

Health workers who owned smartphones were more facile with ALRITE during usability evaluations than those who owned simple mobile phones, moving through the scenarios faster with fewer errors. Importantly, after the first standardized clinical scenario, all health workers spent less time and were more facile using ALRITE on subsequent scenarios without much guidance from the research team. Proficiency with the app was not formally tested.

Health workers provided valuable feedback to improve the usability of ALRITE, including minor changes to the visual display, layout, and flow of the app. For example, health workers recommended larger font for better visualization. They also recommended using a patient age group instead of date of birth for 2 reasons: 1) health workers had difficulty using the calendar

function, and 2) caregivers may not know a child's date of birth, so asking for a child's age group is standard practice.

Provider-specific needs

Another important consideration to ALRITE acceptability is the end user's experience with smartphones. In our study, all health workers owned a mobile phone, of which approximately 60% owned a smartphone. Most who owned a smartphone used social media or communication apps. No health workers we spoke with were using mHealth apps, and only a few had heard of these types of apps.

All those with smartphones preferred that ALRITE be directly downloaded to their personal devices compared to clinic-supplied devices, as they would be more likely to use the app if it were readily available on their own smartphones. Additionally, if health workers used the app on their own smartphones rather than a clinic-supplied device, they said they would be less likely to lose or misplace the device. However, one health worker reminded the group that not everyone has a smartphone, so smartphones would need to be made available to individuals without a personal device. Health workers were pleased that the size of the app was only (27Mb).

The provider's training level was also an important factor. In different levels of health centers in Uganda, there are health workers with varying levels of training and provider roles, ranging from nurse to medical officer. End users with limited clinical training may be more likely to use ALRITE in practice to help with clinical decision-making than others with more training or clinical experience who may not think additional clinical decision support adds value to their clinical care.

> "There are incidences when the doctors are not at the clinic and the nurse needs to make a diagnosis and give treatment as well. ALRITE will save time." HA-001

Provider-patient relationship

Health workers had some concerns regarding ALRITE use in their clinic. Some thought that using the app in front of patients and families would reduce the quality and quantity of personal interaction at a clinic visit. Some also expressed concern that if they used ALRITE to help make clinical decisions, families would lose trust in health workers' ability to diagnose and treat. However, one respondent also suggested that the app could be used as an educational tool for families and help build trust during the visit.

> "The first challenge is on the side of our clients. When you are busy using the app, the client might think you're neglecting her or him and you're busy on WhatsApp, and secondly, a client might think you're not knowledgeable enough since you're using a phone and lose trust in you thinking you don't know what to do… But I think I can start by engaging the patients and informing them that what I am going to do is for your good, I am not just looking for answers but rather improving diagnosis for your child." HW-003-FG2

Clinic-level

Limited resources

High patient volume and limited staffing

At the peri-urban site, 100-300 patients are seen in the ambulatory clinic daily, 60% of which are children (IC-001). Similarly, at the rural site, a stakeholder reported, "we see about 100-200 patients daily… and about 45% of these are children less than 5 years." (IC-003). Stakeholders identified the most common pediatric conditions: malaria, ALRI, and diarrhea. A combination of

clinical officers and nurses without specialty pediatric training see pediatric patients at both sites. The peri-urban site also staffs a few general medical doctors, but they are not always on site. All health workers reported they received IMCI training, from which Uganda Clinical Guidelines are derived.[24] Health workers reported that visit length typically ranges from 10-15 minutes, but a few reported they often take less than 10 minutes.

> "In assessing children, we have a challenge with patient load with few trained health workers who can assess patients. It's a facility in a semi-urban area so the numbers are big with few health workers, and treatment is not always available." HA-001

Limited resources for the diagnosis of pediatric respiratory disease

To diagnose respiratory disease, both sites reported use of stethoscopes, although these are not universally available, nor are they required to use IMCI. They rely on personal watches to count respiratory rate, but not everyone has a watch. Pulse oximetry is not typically available.

> "We have one pulse oximeter in [the operating] theater, but we are currently not using it because it gives confusing results." HA-003

> "It is not a problem [to use a stethoscope], but if it is not available, we resort to the IMCI approach where you depend on a physical exam [without a stethoscope]. In addition, what compromises quality is the number of patients waiting in the line to be reviewed, and you may end up missing out on an important indicator." HW-002-FG3

Limited resources and training affecting adherence to WHO IMCI

All health workers received WHO IMCI training. However, they reported that adherence to IMCI can be challenging for a number of reasons. Firstly, IMCI incorporates respiratory rate and

evaluation of respiratory distress into its clinical decision algorithm. Some health workers reported that counting respiratory rate is impossible without a watch or timer. Secondly, IMCI recommends evaluation of wheezing, but this exam finding is challenging to diagnose, especially without a stethoscope.

> "[Chest] indrawing is easier [to assess] compared to wheezing." HW-001-FG3

> "Monitoring during the care of these children or reassessing the vitals is a challenge." HW-003-FG3

Health workers frequently denied opportunities for robust continuing medical education or refresher trainings for IMCI.

> "We have sent people for IMCI training. We also have a national trainer at the facility who organizes [continuous medical education], but the turnout of health workers is usually not good. Usually, when people do something for many years, they tend to think there is nothing new they can learn." HA-003

Thirdly, availability and use of the IMCI materials are limited in health centers. IMCI can be available in paper or electronic form. However, health workers reported that the paper form is not convenient to use due to the size of the booklet and the likelihood of misplacing it. One health administrator reported that his health center had IMCI installed on a laptop, but the laptop broke and was not replaced.

ALRITE integration into existing health system

Change to workflow

Integrating ALRITE into clinical practice will inevitably change clinic workflow. It may contribute to duplicative work because the current system includes entering data into a written health record. Interestingly, this was not brought up as a concern during focus groups or interviews. Furthermore, using a new technology will be slow at first and may make patient encounters longer rather than shorter in an already busy clinic. Health workers reported that they would need to practice with ALRITE prior to using it with patients to improve work efficiency.

> "At first, it's likely to slow the work because we may be learning the app but with time it will become part of us, and we become part of it so it will ease the work… we need to be familiar with it to help us save time so that patients do not see us take a lot of time on the phones." HW-002-FG2

> "I think we shall have to sort out those with respiratory illnesses at triage which is different from what is being done currently where all patients follow the same assessment route regardless of condition." HW-001-FG1

Furthermore, current practice in Ugandan health centers does not routinely include reassessment of patients after a bronchodilator trial, which is necessary to ascertain whether patients would benefit from treatment with a bronchodilator. Most health workers thought it would be feasible to reassess patients if warranted; however, a few health workers reported that many patients leave after the initial assessment. Lack of reassessment would limit providers' ability to determine bronchodilator responsiveness, an important factor in diagnosing wheezing illnesses and asthma in young children and therefore an important component of ALRITE.

> "We reassess only those who are admitted on the wards. We reassess if the child worsens, but if they are improving, we reassess them the next day during the ward

rounds. I think it's important to integrate the app into the system because it gives reminders about reassessing a patient." HA-001

"There is no opportunity [to reassess children] because most of them come from far and do not usually come back [after treatment is prescribed]." HW-001-FG3

Triage

One current challenge and potential opportunity for ALRITE integration is in patient triage. Health administrators reported no formal triage process to risk-stratify patients as they present to care. There is also no separate pediatric clinic. All patients are seen in the order they arrive, whether adults or children. One health administrator saw ALRITE implementation as an opportunity to establish triage at their health center. He suggested that ALRITE could be used earlier when pediatric patients arrive to the clinic to prioritize those with WHO danger signs and acute respiratory distress.

"[Challenges include] lack of a dedicated clinician to manage children and lack of enough consultation rooms. There is also a knowledge gap in assessing children. We do not have a triage area where we are able to prioritize those with worse conditions. We usually just do visual observation of who is an emergency situation instead of taking medical history and a few vitals. The other issue is we don't differentiate children from adults, they all go through the same entry point… The other [issue] is lack of an emergency unit for children with severe difficulty in breathing." HA-003

Systems-level

Medication shortages impacting ALRITE management

Aside from features of ALRITE itself, we explored other factors that would impact feasibility of ALRITE at a systems level. ALRITE recommends treatment for children with respiratory illnesses, including antibiotics for pneumonia and inhaled bronchodilators with/without systemic corticosteroids for wheezing. Oral salbutamol is generally available at the health centers and sometimes used for children but carries a high side effect profile and is not recommended for acute wheezing in children.[25 26] Health administrator at both sites reported very limited availability of inhaled bronchodilators (2-3 inhalers every 2 months). Health workers may prescribe medications if not available on site, but this requires family members to pay out-of-pocket for prescribed medications at an off-site pharmacy or higher-level health center. Even if ALRITE improves diagnosis of wheezing illness, its impact and feasibility will be greatly limited if appropriate treatment is not readily available.

> "We are not independent when it comes to drugs. Supplies are from National Medical Stores, and they usually give what they have unless you have an independent source outside of the usual supply chain." HA-002

> "The app talks about the bronchodilator, but it doesn't talk about other drugs to give. Here at the low-level facilities we do not have the bronchodilators." HW-002-FG1

Stakeholder buy-in

While not a common theme, one health administrator emphasized the importance of engaging stakeholders early for successful implementation. Specifically, the administrator explained that the Ministry of Health in Uganda and local district health officials would need to approve the app prior to large scale distribution across public and private facilities. Additionally, support at these leadership levels will be critical for widespread uptake and implementation of ALRITE.

DISCUSSION

In this study, we identified key determinants of successful implementation of ALRITE, our mHealth decision support tool, from frontline health workers' perspectives (Figure 2). In addition to ALRITE-specific determinants, health workers and administrators identified important individual-level, clinic-level, and health systems-level determinants and offered innovative ideas for future app development. Overall, these results support ongoing development of ALRITE for potential integration into routine clinical care and underscore the importance of user-centered design early in development prior to implementation of a new technology. ALRITE, if successfully implemented, has the potential to improve childhood morbidity and mortality in three major ways: 1) increased awareness, diagnosis and treatment of wheezing illness, 2) improved IMCI guideline adherence, and 3) effective triage of critically ill infants and children. Potential challenges identified include changes to the provider-patient relationship, time constraints, and medication shortages. However, through thoughtful design and implementation, ALRITE has potential to overcome these challenges by enhancing the provider-patient relationship through education and improved management, improving clinical efficiency through a streamlined process, and increasing supply of life-saving medications such as inhaled bronchodilators through increased awareness, advocacy, and demand.

Previous studies have also evaluated mHealth decision support based on WHO IMCI.[17-19] The predecessor to ALRITE, mPneumonia, demonstrated high acceptability and usability in pilot studies in Ghana.[17 18] Unlike ALRITE, mPneumonia was designed to use on clinic-supplied tablets. Health workers were not as familiar with smartphones and had difficulty navigating the application and general tablet use.[17] Furthermore, health workers expressed potential challenges of mPneumonia including access to electricity and added time to patient encounters.[18] The disparate results between mPneumonia and ALRITE likely reflects interval

improvements in devices and software as well as additional experience with smartphones given growing mobile phone use worldwide.

Two important systematic reviews of health workers' perspectives using mHealth in primary care highlighted similar themes.[21 27] Decision support mHealth tools achieved high acceptability, with health workers reporting increased efficiency, better access to information, and improved adherence to guidelines.[21] Similar to our results, some health workers were concerned mHealth may negatively impact the provider-patient relationship,[21] but this concern has not been evaluated by patients or caregivers. Contrary to our results, some health workers were concerned the algorithm was too prescriptive for clinical decision making.[21] We found that health workers appreciated the simple ALRITE algorithm, which may reflect the limited clinical training in our study population. Additional factors influencing health workers' acceptability of mHealth technologies were cost to the health worker, previous mobile phone experience, and increased time/workload.[27] While our study did not evaluate cost, as ALRITE would be a free application, health workers did appreciate that ALRITE had a small footprint (27 Mb) so would not require much data or take up much smartphone memory. Conversely, health worker perceptions of ALRITE did not change based on prior mobile phone experience, but those with smartphone experience were much more facile with the app.

There has been a recent explosion of digital health tools for use in LMICs, but evidence on effectiveness and scale-up has been lacking.[11 16 28 29] An early human-centered approach to evaluation is critical to better understand determinants for successful implementation and to guide further mHealth design. Therefore, we engaged health administrators and frontline health workers early in the development of ALRITE to better inform acceptability, appropriateness, and feasibility of its use in Ugandan health centers. Through stakeholder interviews, health worker focus groups, and usability evaluations, we not only received important feedback to improve

ALRITE, but also gained a richer understanding of the health setting and potential systems-based and individual level challenges to implementation.

This study had important limitations. First, perceptions of health workers were limited to two health facilities in Uganda. We purposefully chose one peri-urban and one rural health center to better understand differences in resource availability, staffing, and health workers' perceptions. However, there may be additional regional differences in perceptions of and comfort with ALRITE that have yet to be explored. Secondly, it may be possible that we did not capture the full breadth of perspectives, as health workers with dissenting opinions may not have felt comfortable speaking up during focus groups. We tried to address this by probing for dissenting opinions during focus groups and with individual usability evaluations. Thirdly, we did not perform a formal quantitative usability evaluation but rather described general trends and observations. A formal evaluation of end user proficiency was not the objective of this study because the ALRITE app was still in the prototype phase. Finally, health worker perceptions were obtained without experience using ALRITE in clinical practice. This understanding of feasibility in clinical care will be a major focus of future work.

Next steps include updating ALRITE based on user feedback and field testing with frontline health workers. We will also address important potential barriers for implementation, including engaging caregivers, streamlining the ALRITE app to limit any negative effect on existing workflow, developing training programs, ensuring readily available technical support, and engaging key stakeholders at the Uganda Ministry of Health and district health leadership to support further research, medication supply, and ultimate implementation of ALRITE.

CONCLUSION

Taken together, these results provide a detailed, on-the-ground assessment of the opportunities and challenges in the respiratory assessment, diagnosis and treatment of ALRI in young children. Further, the engagement of health workers and richness of data collected support the use of human-centered approaches early-on to identify factors that are pivotal to success of a mHealth application. Finally, our results support the continued development of tailored mHealth tools for decision support in LMICs based on high user acceptability and usability.

Data availability

Data supporting the findings are available within the manuscript. Additional quotes are available upon reasonable request to the corresponding author.

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Author contributions

LEE, MR, JWS, AV, RA, and RN contributed to the concept and study design. AJK developed the mobile health application with mentorship from AV and RA. LEE, IN, and RN coordinated and supervised data collection from the sites. LEE, MR, SAF, IN, BN, and ZN performed data collection. LEE, SAF, and IN analyzed the data, and all authors contributed to interpretation. LEE wrote the draft of the manuscript. RN provided oversight of the project. All authors worked collaboratively to review, edit, and approve the final manuscript.

Competing interests

The authors report no competing interests.

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Figure 1. ALRITE sample screenshots. A) Menu screen. B) Respiratory rate counter. C) Example of diagnosis and treatment recommendations. D) Educational toolkit pop-up on bronchodilator administration. E) Educational toolkit pop-up on stridor.

Figure 2. Frontline health workers' perspectives of determinants of ALRITE implementation.

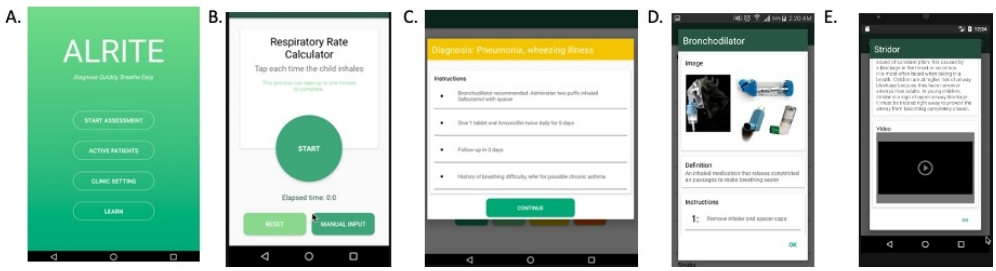

Figure 1. ALRITE sample screenshots. A) Menu screen. B) Respiratory rate counter. C) Example of diagnosis and treatment recommendations. D) Educational toolkit pop-up on bronchodilator administration. E) Educational toolkit pop-up on stridor.

325x87mm (72 x 72 DPI)

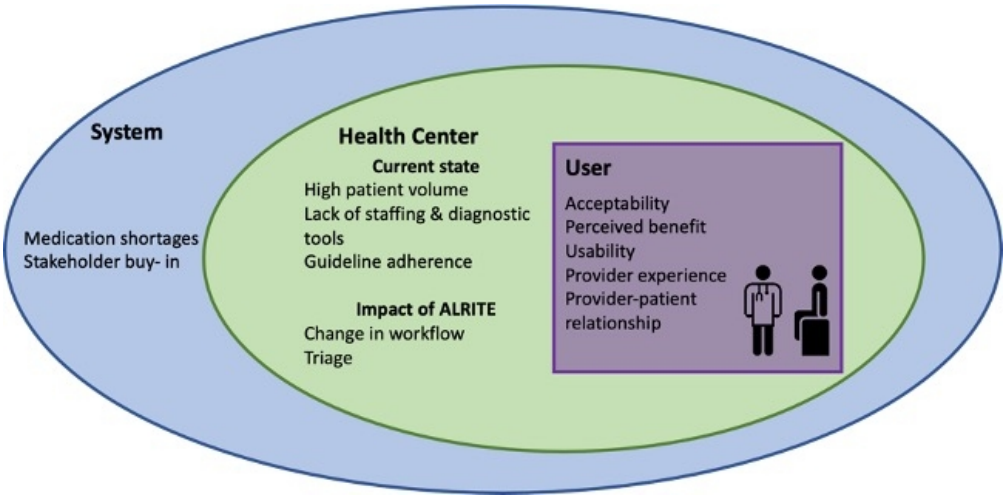

Figure 2. Frontline health workers' perspectives of determinants of ALRITE implementation.

228x112mm (72 x 72 DPI)

Focus Group: Facilitator's Guide

I. Brief demonstration of ALRITE (5 min)

This app is 27 Mb. Would you be willing/interested in downloading?

Outline for focus group

1. Information about your health center
2. Feedback on ALRITE app
3. Feasibility of using app within health setting

II. Basic information

Please raise hand if:

a. you own a mobile phone
b. that mobile phone is a smart phone
c. you regularly use applications on your phone (ex: Facebook, Whatsapp, games…)
d. you have used a mobile health application
e. you have completed the WHO IMCI training

(count and record for each)

Ice breaking questions (choose 1 or 2)

- how often do you see kids compared to adults in your setting?
- What is the typical workflow of children coming into clinic with respiratory complaints? *(how patients move from arrival to discharge and treatment)*
- What are the most common diagnoses that you give to children who come to clinic with respiratory symptoms?
- what kind of equipment and treatments do you have to take care of children with respiratory disease?

III. General comments – ALRITE tool as mobile app (25 min)

- What are your general thoughts about the app?
- What did you think could be improved?
- Is there anything that you would remove from the app? Or add?
- Would this be something you would prefer to have on your personal phone or keep on a hospital phone/tablet?
- How could this app help fill a need in your clinical setting?
- Where do you see challenges with using the app?

IV. Feasibility of ALRITE tool (20 min)

1) Bronchodilator timing and reevaluation.

- Tell us about your experience treating children with inhaled bronchodilators.
- The ALRITE app asks to reassess children after receiving a bronchodilator after 10 minutes. If you give bronchodilators to children, do you typically reassess them afterwards? Tell more about it. What are the challenges to perform a reassessment?

2) Integration into clinical practice

- How do you think using this app would change your workload?
- Do you think this app will change the flow of patients that you described earlier? Please elaborate.
- Biggest challenges/barriers to use?

V. IMCI decision tree & Respiratory assessment (if there is time)

- How does this protocol/decision tree follow how you currently assess patients in your clinic?
- Do you think the application impacts your ability to perform respiratory assessment? If so, how? If not, what would make it more useful?

Closing comments

Introduction to ALRITE & Usability test

Description of ALRITE

ALRITE is a mobile health application that was created to help diagnose and manage acute respiratory illnesses in young children. The goal of the app is to provide decision support to healthcare providers for children with acute respiratory complaints. The app contains a decision tree based on the World Health Organization's (WHO) Integrated Management of Childhood Illness (IMCI) case management guidelines.

One unique addition is that ALRITE will guide you through a respiratory assessment to help decide on whether a bronchodilator trial may be beneficial. Globally, wheezing illnesses are under-recognized and could contribute to severe respiratory illness in young children.

After the assessment, ALRITE will provide most likely diagnoses and treatment recommendations based on the information provided: 1) pneumonia, 2) pneumonia + wheezing illness, 3) severe disease requiring urgent referral/intervention, or 4) upper respiratory infection (supportive care only).

Instructions to participant:

We will ask you to complete a series of tasks using simulated clinical scenarios. There is no time limit or one single solution to completing each task. The study is designed to test the app and not you. You are welcome to ask me any questions that you have while completing the task. There may be times in the study where I do not answer your question because we are interested in seeing how you solve the problem. I will let you know when I cannot answer your question.

As you complete these tasks, we are going to ask you to think aloud as you work. Thinking aloud will help provide us an idea of what you are thinking as you are completing the task. We understand that you may forget to think aloud. If this happens, we ask you to tell us what you are thinking about. After each task is completed, I will ask you a few questions about the task. After all tasks have been completed, I will ask you a few questions about your overall experience of the ALRITE mobile application. If any of the questions are unclear, please ask for clarification.

We ask that during the scenarios, you imagine that you are using the app in the middle of a busy clinical shift and answer the questions as such.

Participant Comments & Feedback

Participant comments are verbal cues that indicate successes and failures in the app. We will record these comments digitally for later review as well as notetaking during the interview. Participants will be asked to answer a brief survey after completing the interview.

Errors

Errors are mistakes that the participants make while using the app that slows or stops the participant from completing each task. This data is critical for fixing errors and increasing efficiency in the app. These errors will be documented by the notetaker.

Scenario 1:

Task 1: Input information provided into the app to determine whether a bronchodilator trial is recommended.

A new patient enters your clinic with the following circumstances:

- *Name: (choose your name)*
- *Female*
- *Birthdate (choose a date where the child is between 4-6 months old)*
- *Alert and playful*
- *Not Vomiting or convulsing*
- *No difficulty eating or drinking*
- *Coughing for 10 days*
- *No HIV exposure risk*
- *This is her third episode of coughing/difficulty breathing episode since birth.*
- *On exam, her temperature is 37.3C. Oxygen saturation 94%. Respiratory rate 64. She has moderate chest indrawing. No Stridor. When you listen with a stethoscope, you hear wheezing when she inhales and exhales.*

Task 2: Read aloud whether a bronchodilator trial is recommended. If recommended, please find the tutorial on how to administer the bronchodilator and talk through how to administer to your patient. Input that you have administered the bronchodilator in the app.

Scenario 2:

Task 3: Input information for the respiratory assessment using the video of a child provided.

A new patient enters your clinic with the following circumstances:

- *Name: (choose a friend's name)*
- *Male*
- *Birthdate (choose a date where the child is 3 years old)*
- *Alert and playful*
- *Not Vomiting or convulsing*
- *No difficulty eating or drinking*
- *Coughing for 7 days*
- *No HIV exposure risk*
- *This is his second episode of coughing/difficulty breathing episode since birth*

Watch video and record respiratory assessment

Task 4: Read aloud whether a bronchodilator trial is recommended. Then close the encounter and return to the home screen.

Scenario 3:

Task 5: Return to your first patient's encounter (Scenario 1). Is she ready for re-assessment? How do you know?

If ready, please input her follow up examination outlined below.

- *Name: (your name)*
- *After the bronchodilator, she seems to be breathing a little easier than before the trial. On exam, her oxygen saturation 95%. Respiratory rate 54. She has mild chest indrawing. She still has wheezing but only when she exhales.*

Task 6: Talk through the diagnosis and treatment recommendations provided by the app.

Reporting checklist for qualitative study.

Based on the SRQR guidelines.

		Reporting Item	Page Number
Title			
	#1	Concise description of the nature and topic of the study identifying the study as qualitative or indicating the approach (e.g. ethnography, grounded theory) or data collection methods (e.g. interview, focus group) is recommended	1
Abstract			
	#2	Summary of the key elements of the study using the abstract format of the intended publication; typically includes background, purpose, methods, results and conclusions	2
Introduction			
Problem formulation	#3	Description and signifcance of the problem / phenomenon studied: review of relevant theory and empirical work; problem statement	4-5
Purpose or research question	#4	Purpose of the study and specific objectives or questions	5
Methods			
Qualitative approach and research paradigm	#5	Qualitative approach (e.g. ethnography, grounded theory, case study, phenomenolgy, narrative research) and guiding theory if appropriate; identifying the research paradigm (e.g. postpositivist, constructivist / interpretivist) is also recommended; rationale. The rationale should briefly discuss the justification for choosing that theory, approach, method or technique rather than other options available; the assumptions and limitations implicit in those choices and how those choices influence study conclusions and	8

		transferability. As appropriate the rationale for several items might be discussed together.	
Researcher characteristics and reflexivity	#6	Researchers' characteristics that may influence the research, including personal attributes, qualifications / experience, relationship with participants, assumptions and / or presuppositions; potential or actual interaction between researchers' characteristics and the research questions, approach, methods, results and / or transferability	7-8
Context	#7	Setting / site and salient contextual factors; rationale	5-6
Sampling strategy	#8	How and why research participants, documents, or events were selected; criteria for deciding when no further sampling was necessary (e.g. sampling saturation); rationale	6,8
Ethical issues pertaining to human subjects	#9	Documentation of approval by an appropriate ethics review board and participant consent, or explanation for lack thereof; other confidentiality and data security issues	9
Data collection methods	#10	Types of data collected; details of data collection procedures including (as appropriate) start and stop dates of data collection and analysis, iterative process, triangulation of sources / methods, and modification of procedures in response to evolving study findings; rationale	7-9
Data collection instruments and technologies	#11	Description of instruments (e.g. interview guides, questionnaires) and devices (e.g. audio recorders) used for data collection; if / how the instruments(s) changed over the course of the study	7, supplement
Units of study	#12	Number and relevant characteristics of participants, documents, or events included in the study; level of participation (could be reported in results)	9
Data processing	#13	Methods for processing data prior to and during analysis, including transcription, data entry, data management and security, verification of data integrity, data coding, and anonymisation / deidentification of excerpts	7
Data analysis	#14	Process by which inferences, themes, etc. were identified and developed, including the researchers involved in data analysis; usually references a specific paradigm or approach; rationale	8

Techniques to enhance trustworthiness	#15	Techniques to enhance trustworthiness and credibility of data analysis (e.g. member checking, audit trail, triangulation); rationale	8
Results/findings			
Syntheses and interpretation	#16	Main findings (e.g. interpretations, inferences, and themes); might include development of a theory or model, or integration with prior research or theory	9-19
Links to empirical data	#17	Evidence (e.g. quotes, field notes, text excerpts, photographs) to substantiate analytic findings	10-19
Discussion			
Intergration with prior work, implications, transferability and contribution(s) to the field	#18	Short summary of main findings; explanation of how findings and conclusions connect to, support, elaborate on, or challenge conclusions of earlier scholarship; discussion of scope of application / generalizability; identification of unique contributions(s) to scholarship in a discipline or field	20-22
Limitations	#19	Trustworthiness and limitations of findings	22
Other			
Conflicts of interest	#20	Potential sources of influence of perceived influence on study conduct and conclusions; how these were managed	24
Funding	#21	Sources of funding and other support; role of funders in data collection, interpretation and reporting	24

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Health workers' perspectives of a mobile health tool to improve diagnosis and management of pediatric acute respiratory illnesses in Uganda: A qualitative study

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Health workers' perspectives of a mobile health tool to improve diagnosis and management of pediatric acute respiratory illnesses in Uganda: A qualitative study

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Abstract

Objectives: Mobile health tools have potential to improve the diagnosis and management of acute lower respiratory illnesses (ALRI), a leading cause of pediatric mortality worldwide. The objectives were to evaluate health workers' perceptions of acceptability, usability, and feasibility of ALRITE, a novel mobile health tool to help frontline health workers diagnose, treat and provide education about ALRI in children <5 years.

Design: A qualitative study including semi-structured interviews with health facility administrators and focus groups with primary care health workers.

Setting: Two federally funded Ugandan primary care health facilities, one peri-urban and one rural.

Participants: We enrolled 3 health administrators and 28 health workers (clinical officers and nurses).

Intervention: The ALRITE smartphone application was developed to help frontline health workers adhere to ALRI guidelines and differentiate wheezing illnesses from pneumonia in children under 5 years of age. ALRITE contains a simple decision tree, a partially automated respiratory rate counter, educational videos, and an adapted respiratory assessment score to determine bronchodilator responsiveness. We performed a demonstration of ALRITE for participants at the beginning of interviews and focus groups. No participant had used ALRITE prior.

Results: Themes impacting the potential implementation of ALRITE were organized using individual-level, clinic-level, and health-system level determinants. Individual-level determinants were acceptability and perceived benefit, usability, provider needs, and provider-patient relationship. Clinic-level determinants were limited resources and integration within the health center. Systems-level determinants included medication shortages and stakeholder engagement.

Conclusions: Incorporation of these themes will ready ALRITE for field testing. Early engagement of end-users provides insights critical to the development of tailored mHealth decision support tools.

Strengths and limitations of this study

- By using a technology probe and human-centered participatory approach early in mHealth development, we engaged participants and gathered information not only about the ALRITE tool but also contextual factors that are pivotal to the ultimate success of a mHealth application in this setting
- We partnered with local health officials in the planning phase to encourage health worker attendance to information sessions, which translated to enrolling almost all eligible health workers, thus providing a more accurate and complete assessment at each study site
- This study was limited by perspectives at two health centers, which may not reflect regional differences in resource availability, staffing, and health workers' perceptions.
- Health worker perceptions were obtained without experience using ALRITE in clinical practice, which will be a focus of future work.
- We acknowledge that key team members who participated in all aspects of this project are American physicians/researchers who bring a different set of experiences and lens to this work, which may have influenced participants' responses and interpretation, but American team members worked in close partnership with Ugandan team members to ensure shared decision-making and engagement with study participants.

Keywords: Community child Health, international health services, paediatric thoracic medicine, respiratory infections, qualitative research, public health, mobile health

INTRODUCTION

Acute lower respiratory illnesses (ALRI) remain a leading cause of mortality in children under 5, responsible for 15% of all deaths in this age range.[1 2] Over 800,000 young children worldwide die of ALRI each year; 500,000 of these deaths occur in sub-Saharan Africa.[1-5] In Uganda, ALRI is responsible for 11% deaths in children under 5.[5 6] ALRI encompass multiple disease processes that include bacterial pneumonia, viral pneumonia, and wheezing illnesses. Differentiating between these diseases and choosing the appropriate treatment plan is challenging, especially where skilled personnel and diagnostic tools are lacking. The World Health Organization (WHO) Integrated Management of Childhood Illnesses (IMCI) provides guidelines for ALRI diagnosis and management, with emphasis on pneumonia and treatment with antibiotics. The IMCI was updated in 2014 to include assessment of wheezing and treatment with inhaled bronchodilators,[7] but wheezing illness remains underdiagnosed and undertreated in low- and middle-income countries (LMICs).[8,9]

Mobile phone use recently surpassed two-thirds of the global population and over 70% in Uganda[10], offering opportunities for digital health tools to enhance adherence to guidelines and build capacity through clinician education.[11-16] Importantly, small pilot studies of mHealth tools based on WHO IMCI ALRI guidelines demonstrated promising preliminary results but have not addressed wheezing illness.[17-20] To promote responsible, sustainable, and high impact mHealth interventions in LMICs, the WHO recently released digital health guidelines recommending high quality research in fields of decision support and education.[21]

We developed the Acute Lower Respiratory Illness Treatment and Evaluation (ALRITE) mHealth application as a decision support tool to aid frontline health workers to improve diagnosis and treatment of ALRI in children under 5 years of age, with a particular focus on distinguishing wheezing illness from pneumonia. In order to address potential challenges with

widespread ALRITE use, this study sought to understand determinants of successful ALRITE implementation from the end users' perspective. The objective of this study was to evaluate health workers' perceptions of feasibility, usability, and acceptability of the ALRITE mHealth tool in two Ugandan primary care health centers. This user-centered, formative approach will inform further development of a locally relevant decision support tool to improve the diagnosis and treatment of ALRI in Ugandan health centers.

METHODS

Study design

This study uses a human-centered, or participatory, approach to examine frontline health workers' perceptions of ALRITE and its impact on their workflows and patient care. We developed an initial prototype of ALRITE and used it as a technology probe to gather insights about its feasibility, usability, and acceptability. Technology probes are defined as instruments to "[collect] information about the use and users of the technology in a real-world setting", improve the intervention's design by meeting the needs and wishes of the user, and field-test.[22] We used an exploratory qualitative study design to allow for deeper exploration into feasibility, usability, and acceptability for the purposes of 1) improving the mHealth tool, 2) identifying barriers/facilitators beyond the tool itself to inform feasibility and implementation strategies, and 3) determining quantitative outcomes measures for future studies (qual to QUAN mixed methods approach).[23] The research team determined that quantitative survey data would have been inadequate to answer our research questions due to lack of depth, opportunity to probe, and concerns about social desirability bias.

We conducted in-depth semi-structured interviews with health facility administrators to understand clinic context, availability of resources, challenges, day-to-day operations, and feasibility of ALRITE from a systems standpoint (Supplementary Material). We conducted focus

groups with primary care health workers (clinical officers and nurses) to understand how participants respond to peer responses and the forces that may influence their thinking and behavior around the app, how this would affect patient-provider interactions, and their reactions towards technology. All health worker participants had time to practice using ALRITE with clinical scenarios (Supplementary Material) before focus groups to give participants a better understanding of the app, its content, and usability to better inform their focus group responses.

Study sites

Both study sites were federally funded Health Center IV in Jinja district, Uganda and offer free healthcare. The peri-urban site is located 15 minutes driving from the city center of Jinja, the second largest city in Uganda, and the rural site is located 45-60 minutes driving from Jinja. Both sites have inpatient and outpatient facilities and an operating theater for obstetrics and urgent surgical cases.

The health care delivery system in Uganda has 6 levels that build on the previous level: 1) Health Center II provides basic outpatient care; 2) Health Center III has maternity services; 3) Health Center IV has primary care, basic inpatient facilities and emergency obstetric care; 4) District Hospitals have general surgery, dental services, and diagnostic services (i.e. chest radiography and laboratory); 5) Regional Referral Hospitals have specialized care; 6) National Referral Hospital has additional specialized and sub-specialized services.

The two specific Health Center IV were selected for this study based on prior research indicating that 1) adherence to IMCI was low, 2) consultations were performed by health workers with limited training, 3) antibiotics were over-prescribed, and 4) inhaled bronchodilators for wheezing illness were not prescribed.[9]

Participants

We recruited at least 1 health administrator for semi-structured interviews from each study site. Health administrators were clinicians (medical doctors or clinical officers) who serve a director role in leadership and staff supervision at an individual health center, termed locally as “health facility in-charges”. Eligible participants for focus groups were health workers (clinical officers or nurses) who had been working at the study site for at least 6 months and were responsible for outpatient care of children. None had used ALRITE prior. Clinical officers complete a three-year diploma course in clinical medicine. Nurses in these health centers primarily act as clinicians due to staff shortages and task shifting. Prior to data collection, research team members met with officials at the Jinja District Health Office for approval, plan for disseminating study information to participating study sites, and scheduling days for recruitment and data collection. Information sessions were coordinated with help from health administrators at each study site to maximize participation. All health workers were notified about the session dates one week in advance and were invited to attend the information session even if not scheduled to work that day. The study team employed in-person information sessions for recruitment using convenience sampling. Sample size was determined by the number of health workers who showed up the scheduled days of data collection with the goal of recruiting all eligible health workers at each study site. All participants provided a written informed consent in English for their participation.

ALRITE mHealth tool

Based on a previous mHealth tool, mPneumonia[17 18], the ALRITE mHealth application was developed for smartphones to help frontline health workers adhere to IMCI guidelines and differentiate wheezing illnesses from pneumonia in children under 5 years of age. ALRITE contains a simple decision tree, a partially automated respiratory rate counter, educational videos (brief clips providing examples of children in respiratory distress), and an adapted

respiratory assessment score to determine bronchodilator responsiveness (Figure 1). The algorithm walks the user through basic demographics, IMCI danger signs, medical history, physical exam, and bronchodilator assessment (if appropriate). The final diagnoses include *severe pneumonia or very severe disease, pneumonia +/-, wheezing illness, and cough or cold +/- wheezing illness.* The WHO classification does not include a separate diagnosis of "wheezing illness" but rather includes the diagnosis and treatment of wheezing as additional recommendations for the diagnoses of "pneumonia" and "cough or cold". [7] We added the term "wheezing illness" to ALRITE diagnoses to prompt health workers to provide bronchodilators and refer for further assessment as necessary. The app is 27 MB and was downloaded on supplied Android smartphones for study use.

Data collection and management

Prior to data collection, research assistants were trained and pretested focus group/interview guides through simulations with the research team. Demographic information was collected first on paper forms, then transferred to REDCap (Research Electronic Data Capture).[24] Unique identifiers were used for each participant. Focus groups and interviews were performed primarily in English over the course of one week using interview/focus group guides (Supplementary information). Prior to focus groups, all health worker participants were given time to practice using ALRITE by going through at least 2 clinical scenarios individually or in small groups of up to 3 people (Supplementary information), while members of the study team (LEE, IN, MR, SAF, BN, ZN) asked for specific feedback, answered questions about the app, and took notes. We performed a demonstration of ALRITE for participants at the beginning of interviews and focus groups. Ugandan research assistants did provide clarifications and some probing in the local language; some participant responses were given in the local language and translated to English for the study notes. All interviews and focus groups were digitally recorded, deidentified, and transcribed into English without identifiers by IN, who is fluent in English and

the local language. Transcriptions were reviewed by IN and LEE for content and cultural accuracy. Members of the study team (LEE, IN, MR, SAF) took notes during focus groups and interviews to augment and clarify the transcribed notes. Hard copy data were securely transported to Makerere University Lung Institute (Kampala, Uganda) for secure storage. No personal data will be transferred from the primary institution in Kampala, Uganda.

Study team

This was an international collaboration, including experts in public health, pulmonology/asthma, information and communication technology for development, human-computer interaction, and community-based interventions. Research assistants BN and ZN from Uganda experienced in qualitative interviewing and fluent in the local language led focus groups and interviews with the guidance of LEE, a content expert in the ALRITE app with previous qualitative experience in technology implementation. SAF provided qualitative expertise in design, data collection, and analysis. RN provided local expertise in health systems, qualitative design and interview guides, and pediatrics. IN provided local research coordination and knowledge of the health system. Pediatric expertise was provided by RN and JS with additional pediatric pulmonology expertise by MR and LEE. RA was instrumental in the design of mPneumonia and senior author on both manuscripts.[17 18] ALRITE app design and development was performed by AK, AV, and RA, with additional expertise in usability testing and human-centered design by AV. We acknowledge that key team members who participated in all aspects of this project are American physicians and researchers who bring a different set of experiences and lens to this work, and that our positionality may have influenced participants' responses and interpretation. Working in partnership with our Ugandan team was critical to ensure shared decision-making and our ability to work closely with the clinicians.

Analysis

We analyzed our detailed notes and transcripts using a deductive thematic approach, whereby the researchers LEE, SAF, and IN examined the data to identify common themes for each of the research questions based on a similar framework of a previously published mHealth technology.[17 18] During the analysis, the team documented outlier or dissenting perspectives in order to provide a more complete picture of participant responses to ALRITE. First, LEE and SAF read through each of the transcripts and set of notes and then we developed a provisional framework based on primary research questions. LEE, SAF, MR, IN, BN, and ZN held team meetings following each day of data collection to compile notes, review emerging themes, and refine the coding framework. Codes were aggregated into major themes and subthemes by first annotating an online document of transcripts, then reorganizing into a separate document, similar to but without the use of coding software. Additional meetings with the research team allowed for further refinement of themes and subthemes. Transcripts were reread to ensure that preliminary results represented the majority of user feedback. The quotes were chosen to confirm and highlight themes and introduce diverging viewpoints not previously captured. The Standards for Reporting Qualitative Research (SRQR) were used to guide reporting.[25]

Ethics

The study was approved by the Mulago Hospital Research and Ethics Committee and Uganda National Council for Science and Technology (HS2692). The study was reviewed and received exempt status from the University of Washington (STUDY0007895). Written informed consent was obtained from all participants in accordance with international and local regulations.

Patient and Public involvement

While not involved in the initial design, conduct, or reporting, study participants are involved in ultimate design and implementation of the intervention and are included in the dissemination plan, along with district- and national-level health system members and patient caregivers.

RESULTS

Participant & setting characteristics

In January 2020, we enrolled 28 healthcare provider participants across 2 health centers in Uganda. Key stakeholders, including 3 health administrators (HA), took part in individual in-depth interviews, while 5 clinical officers and 20 nurses (HW) took part in 3 focus groups (Table 1). Based on recommendations from the health administrators from each site, we conducted separate focus groups for clinical officers (n=3) and nurses (n=10) at the peri-urban site to limit concern for potential power dynamic, but this was not deemed a concern at the rural site where one focus group was recommended. Interviews were approximately 30 minutes long, while focus groups were approximately 1.5 hours in length.

Table 1. Participant characteristics

	Rural Site	Peri-urban Site
In-depth interviews	**n=1**	**n=2**
Role		
Medical officer	0	2
Clinical officer	1	0
Male	1	2
Focus groups	***n=12***	***n=13***
Role		
Clinical officer	2	3
Nurse	10	10
Female	9	10
Age		
<30 years	5	5
30-40 years	5	6
>40 years	2	2
Experience in health care, years		
< 5	2	3
5-10	8	4
> 10	2	6

We identified several themes impacting the development and implementation of ALRITE in Ugandan health centers from the perspective of health administrators and frontline health

workers. Themes were organized by a social ecological model of determinants: individual, clinic, and health system (Figure 2). Individual-level determinants were acceptability and perceived benefit, usability, provider needs, and provider-patient relationship. Clinic-level determinants were limited resources, integration within the health center. Systems-level determinants included medication shortages and stakeholder engagement. Each theme is presented below in greater detail and with direct quotes that typify respondent comments.

Individual-level

Acceptability & perceived benefit of ALRITE

All health workers indicated they would like to have ALRITE available to use in their healthcare setting. Health workers also reported that they appreciated that ALRITE reminded them of important medical questions to ask and key components of the physical exam.

> "It helps us to remember the clear assessment of these children because at times you are rushing and forget to assess something. You go with what you see quickly, but the app gives you the procedure to follow. It also helps in giving the right doses." HW-002-FG2

They responded positively to the integrated respiratory rate counter. Health workers' eagerness to learn was apparent during focus groups and interviews. Indeed, many health workers reported the educational videos were one of their favorite features of ALRITE. In addition to data gathering, health workers liked the information management capabilities, including medication dosing, which is generally age- or weight-based for children.

> "The part of the app that I like mainly are the videos. It is good because it helps diagnosing and guides through the right treatment hence saving patient time." HA-001

> "[The respiratory rate counter] is convenient because you may not have a watch." HW-007-FG3.

It is important to acknowledge the novelty of ALRITE as a mHealth app technology likely contributed to high acceptability by health workers as well.

> "[Providers] usually like new technology, I think they will be excited to use it and therefore they are likely to download [the app]. In addition, people prefer digital information than opening and reading what is in the [IMCI] book." HA-003

Respondents had ideas for improving acceptability, appropriateness, and potential benefit of ALRITE. Health workers asked for additional automated or semi-automated smartphone tools, such as pulse oximetry or digital auscultation to be integrated into ALRITE. Multiple health workers commented on the potential for storage of clinical information. One health worker wanted to use it as a personal quality control device to review his previous diagnoses and treatment plans. A few wanted the app expanded to other disease processes and age groups. Some health workers suggested incorporating additional educational components targeted to patients and families. One health worker suggested incorporating risk stratification for children with chronic disease and environmental risk factors (i.e. smoke exposure, crowded housing) in order to focus on prevention.

> "[In the app], we are missing [a question on] the type of fuel used at home to cook and source of light. Some produce a lot of smoke. [By offering recommendations, families] can change the way of cooking, hence reducing exposures. This could help in prevention [of respiratory diseases]. We therefore can make a recommendation and follow up in about 6 months." HW-005-FG3

ALRITE usability

We defined usability as "the design factors that affect the user experience of operating the application's device and navigating the application for its intended purpose."[18] ALRITE features that contributed to a positive user experience included overall design, simplicity, flow, and clarity of diagnosis. Generally, health workers thought the app was easy to follow and would be quick to get to diagnosis.

> "It saves time. You diagnose very fast and you are able to know the treatment to give so it improves on the appropriate management of patients." HW-001-FG1

When given the opportunity to use the mHealth tool, health workers who owned smartphones were more facile with ALRITE than those who owned simple mobile phones. Importantly, after practicing with ALRITE and receiving coaching from the research team, all health workers became more facile using ALRITE. Proficiency with the app was not formally tested.

Health workers provided valuable feedback to improve the usability of ALRITE, including minor changes to the visual display, layout, and flow of the app. For example, health workers recommended larger font for better visualization. They also recommended using a patient age group instead of date of birth for 2 reasons: 1) health workers had difficulty using the calendar

function, and 2) caregivers may not know a child's date of birth, so asking for a child's age group is standard practice.

Provider-specific needs

Another important consideration to ALRITE acceptability is the end user's experience with smartphones. In our study, all health workers owned a mobile phone, of which approximately 60% owned a smartphone. Most who owned a smartphone used social media or communication apps. No health workers we spoke with were using mHealth apps, and only a few had heard of these types of apps.

All those with smartphones preferred that ALRITE be directly downloaded to their personal devices compared to clinic-supplied devices, as they would be more likely to use the app if it were readily available on their own smartphones. Additionally, if health workers used the app on their own smartphones rather than a clinic-supplied device, they said they would be less likely to lose or misplace the device. However, one health worker reminded the group that not everyone has a smartphone, so smartphones would need to be made available to individuals without a personal device. Health workers were pleased that the size of the app was only (27Mb).

The provider's training level was also an important factor. In different levels of health centers in Uganda, there are health workers with varying levels of training and provider roles, ranging from nurse to medical officer. End users with limited clinical training may be more likely to use ALRITE in practice to help with clinical decision-making than others with more training or clinical experience who may not think additional clinical decision support adds value to their clinical care.

> "There are incidences when the doctors are not at the clinic and the nurse needs to make a diagnosis and give treatment as well. ALRITE will save time." HA-001

Provider-patient relationship

Health workers had some concerns regarding ALRITE use in their clinic. Some thought that using the app in front of patients and families would reduce the quality and quantity of personal interaction at a clinic visit. Some also expressed concern that if they used ALRITE to help make clinical decisions, families would lose trust in health workers' ability to diagnose and treat. However, one respondent also suggested that the app could be used as an educational tool for families and help build trust during the visit.

> "The first challenge is on the side of our clients. When you are busy using the app, the client might think you're neglecting her or him and you're busy on WhatsApp, and secondly, a client might think you're not knowledgeable enough since you're using a phone and lose trust in you thinking you don't know what to do… But I think I can start by engaging the patients and informing them that what I am going to do is for your good, I am not just looking for answers but rather improving diagnosis for your child." HW-003-FG2

Clinic-level

Limited resources

High patient volume and limited staffing

At the peri-urban site, 100-300 patients are seen in the ambulatory clinic daily, 60% of which are children (IC-001). Similarly, at the rural site, a stakeholder reported, "we see about 100-200 patients daily… and about 45% of these are children less than 5 years." (IC-003). Stakeholders identified the most common pediatric conditions: malaria, ALRI, and diarrhea. A combination of

clinical officers and nurses without specialty pediatric training see pediatric patients at both sites. The peri-urban site also staffs a few general medical doctors, but they are not always on site. All health workers reported they received IMCI training, from which Uganda Clinical Guidelines are derived.[26] Health workers reported that visit length typically ranges from 10-15 minutes, but a few reported they often take less than 10 minutes.

> "In assessing children, we have a challenge with patient load with few trained health workers who can assess patients. It's a facility in a semi-urban area so the numbers are big with few health workers, and treatment is not always available." HA-001

Limited resources for the diagnosis of pediatric respiratory disease

To diagnose respiratory disease, both sites reported use of stethoscopes, although these are not universally available, nor are they required to use IMCI. They rely on personal watches to count respiratory rate, but not everyone has a watch. Pulse oximetry is not typically available.

> "We have one pulse oximeter in [the operating] theater, but we are currently not using it because it gives confusing results." HA-003

> "It is not a problem [to use a stethoscope], but if it is not available, we resort to the IMCI approach where you depend on a physical exam [without a stethoscope]. In addition, what compromises quality is the number of patients waiting in the line to be reviewed, and you may end up missing out on an important indicator." HW-002-FG3

Limited resources and training affecting adherence to WHO IMCI

All health workers received WHO IMCI training. However, they reported that adherence to IMCI can be challenging for a number of reasons. Firstly, IMCI incorporates respiratory rate and

evaluation of respiratory distress into its clinical decision algorithm. Some health workers reported that counting respiratory rate is impossible without a watch or timer. Secondly, IMCI recommends evaluation of wheezing, but this exam finding is challenging to diagnose, especially without a stethoscope.

> "[Chest] indrawing is easier [to assess] compared to wheezing." HW-001-FG3

> "Monitoring during the care of these children or reassessing the vitals is a challenge." HW-003-FG3

Health workers frequently denied opportunities for robust continuing medical education or refresher trainings for IMCI.

> "We have sent people for IMCI training. We also have a national trainer at the facility who organizes [continuous medical education], but the turnout of health workers is usually not good. Usually, when people do something for many years, they tend to think there is nothing new they can learn." HA-003

Thirdly, availability and use of the IMCI materials are limited in health centers. IMCI can be available in paper or electronic form. However, health workers reported that the paper form is not convenient to use due to the size of the booklet and the likelihood of misplacing it. One health administrator reported that his health center had IMCI installed on a laptop, but the laptop broke and was not replaced.

ALRITE integration into existing health system

Change to workflow

Integrating ALRITE into clinical practice will inevitably change clinic workflow. It may contribute to duplicative work because the current system includes entering data into a written health record. Interestingly, this was not brought up as a concern during focus groups or interviews. Furthermore, using a new technology will be slow at first and may make patient encounters longer rather than shorter in an already busy clinic. Health workers reported that they would need to practice with ALRITE prior to using it with patients to improve work efficiency.

> "At first, it's likely to slow the work because we may be learning the app but with time it will become part of us, and we become part of it so it will ease the work… we need to be familiar with it to help us save time so that patients do not see us take a lot of time on the phones." HW-002-FG2

> "I think we shall have to sort out those with respiratory illnesses at triage which is different from what is being done currently where all patients follow the same assessment route regardless of condition." HW-001-FG1

Furthermore, current practice in Ugandan health centers does not routinely include reassessment of patients after a bronchodilator trial, which is necessary to ascertain whether patients would benefit from treatment with a bronchodilator. Most health workers thought it would be feasible to reassess patients if warranted; however, a few health workers reported that many patients leave after the initial assessment. Lack of reassessment would limit providers' ability to determine bronchodilator responsiveness, an important factor in diagnosing wheezing illnesses and asthma in young children and therefore an important component of ALRITE.

> "We reassess only those who are admitted on the wards. We reassess if the child worsens, but if they are improving, we reassess them the next day during the ward

rounds. I think it's important to integrate the app into the system because it gives reminders about reassessing a patient." HA-001

"There is no opportunity [to reassess children] because most of them come from far and do not usually come back [after treatment is prescribed]." HW-001-FG3

Triage

One current challenge and potential opportunity for ALRITE integration is in patient triage. Health administrators reported no formal triage process to risk-stratify patients as they present to care. There is also no separate pediatric clinic. All patients are seen in the order they arrive, whether adults or children. One health administrator saw ALRITE implementation as an opportunity to establish triage at their health center. He suggested that ALRITE could be used earlier when pediatric patients arrive to the clinic to prioritize those with WHO danger signs and acute respiratory distress.

"[Challenges include] lack of a dedicated clinician to manage children and lack of enough consultation rooms. There is also a knowledge gap in assessing children. We do not have a triage area where we are able to prioritize those with worse conditions. We usually just do visual observation of who is an emergency situation instead of taking medical history and a few vitals. The other issue is we don't differentiate children from adults, they all go through the same entry point… The other [issue] is lack of an emergency unit for children with severe difficulty in breathing." HA-003

Systems-level

Medication shortages impacting ALRITE management

Aside from features of ALRITE itself, we explored other factors that would impact feasibility of ALRITE at a systems level. ALRITE recommends treatment for children with respiratory illnesses, including antibiotics for pneumonia and inhaled bronchodilators with/without systemic corticosteroids for wheezing. Oral salbutamol is generally available at the health centers and sometimes used for children but carries a high side effect profile and is not recommended for acute wheezing in children.[27 28] Health administrator at both sites reported very limited availability of inhaled bronchodilators (2-3 inhalers every 2 months). Health workers may prescribe medications if not available on site, but this requires family members to pay out-of-pocket for prescribed medications at an off-site pharmacy or higher-level health center. Even if ALRITE improves diagnosis of wheezing illness, its impact and feasibility will be greatly limited if appropriate treatment is not readily available.

> "We are not independent when it comes to drugs. Supplies are from National Medical Stores, and they usually give what they have unless you have an independent source outside of the usual supply chain." HA-002

> "The app talks about the bronchodilator, but it doesn't talk about other drugs to give. Here at the low-level facilities we do not have the bronchodilators." HW-002-FG1

Stakeholder buy-in

While not a common theme, one health administrator emphasized the importance of engaging stakeholders early for successful implementation. Specifically, the administrator explained that the Ministry of Health in Uganda and local district health officials would need to approve the app prior to large scale distribution across public and private facilities. Additionally, support at these leadership levels will be critical for widespread uptake and implementation of ALRITE.

DISCUSSION

In this study, we identified key determinants towards successful implementation of ALRITE, our mHealth decision support tool, from frontline health workers' perspectives (Figure 2). In addition to ALRITE-specific determinants, health workers and administrators identified important individual-level, clinic-level, and health systems-level determinants and offered innovative ideas for future app development. Overall, these results support ongoing development of ALRITE for potential integration into routine clinical care and underscore the importance of user-centered design early in development prior to implementation of a new technology. ALRITE, if successfully implemented, has the potential to improve childhood morbidity and mortality in three major ways: 1) increased awareness, diagnosis and treatment of wheezing illness, 2) improved IMCI guideline adherence through prompts and education, and 3) effective triage of critically ill infants and children. Potential challenges identified include changes to the provider-patient relationship, time constraints, and medication shortages. However, through thoughtful design and implementation, ALRITE has potential to overcome these challenges by enhancing the provider-patient relationship through education and improved management, improving clinical efficiency through a streamlined process, and increasing supply of life-saving medications such as inhaled bronchodilators through increased awareness, advocacy, and demand.

Additional strengths of the study include using a technology probe and human-centered, participatory approach early in mHealth development to engage participants and gather information not only about the specific mHealth tool but also to build an underpinning knowledge of factors that are pivotal to the ultimate success of a mHealth application. We partnered with local health officials in the planning phase to encourage health worker attendance to information sessions, which translated in almost all eligible health workers at each site participating in the study to provide a more accurate and complete on-the-ground assessment at each study site.

We also included health administrators as participants to provide a broader understanding of the clinic context, challenges, day-to-day operations, and feasibility of ALRITE from a systems standpoint, adding a unique perspective to the health workers' responses.

Previous studies have also evaluated mHealth decision support based on WHO IMCI.[17-19] The predecessor to ALRITE, mPneumonia, demonstrated high acceptability and usability in pilot studies in Ghana.[17 18] Unlike ALRITE, mPneumonia was designed to use on clinic-supplied tablets. Health workers were not as familiar with smartphones and had difficulty navigating the application and general tablet use.[17] Furthermore, health workers expressed potential challenges of mPneumonia including access to electricity and added time to patient encounters.[18] The disparate results between mPneumonia and ALRITE likely reflects interval improvements in devices and software as well as additional experience with smartphones given growing mobile phone use worldwide.

Two important systematic reviews of health workers' perspectives using mHealth in primary care highlighted similar themes.[21 29] Decision support mHealth tools achieved high acceptability, with health workers reporting increased efficiency, better access to information, and improved adherence to guidelines.[21] Similar to our results, some health workers were concerned mHealth may negatively impact the provider-patient relationship,[21] but this concern has not been evaluated by patients or caregivers. Contrary to our results, some health workers were concerned the algorithm was too prescriptive for clinical decision making.[21] We found that health workers appreciated the simple ALRITE algorithm, which may reflect the limited clinical training in our study population. Additional factors influencing health workers' acceptability of mHealth technologies were cost to the health worker, previous mobile phone experience, and increased time/workload.[29] While our study did not evaluate cost, as ALRITE would be a free application, health workers did appreciate that ALRITE had a small footprint (27 Mb) so would not require

much data or take up much smartphone memory. Conversely, health worker perceptions of ALRITE did not change based on prior mobile phone experience, but those with smartphone experience were much more facile with the app.

There has been a recent explosion of digital health tools for use in LMICs, but evidence on effectiveness and scale-up has been lacking.[11 16 30 31] An early human-centered approach to evaluation is critical to better understand determinants of successful implementation and to guide further mHealth design. Therefore, we included health administrators and frontline health workers early in the development of ALRITE as participants to better inform acceptability, appropriateness, and feasibility of its use in Ugandan health centers. Through stakeholder interviews and health worker focus groups, we not only received important feedback to improve ALRITE, but also gained a richer understanding of the health setting and potential systems-based and individual level challenges to implementation.

This study had important limitations. First, perceptions of health workers were limited to two health facilities in Uganda. We purposefully chose one peri-urban and one rural health center to better understand differences in resource availability, staffing, and health workers' perceptions. However, there may be additional regional differences in perceptions of and comfort with ALRITE that have yet to be explored. Secondly, it may be possible that we did not capture the full breadth of perspectives, as health workers with dissenting opinions may not have felt comfortable speaking up during focus groups. We tried to address this by probing for dissenting opinions during focus groups and while health workers were practicing with the app in smaller groups. Thirdly, we did not perform formal quantitative usability evaluations. A formal evaluation of end user proficiency was not the objective of this study because the ALRITE app was still in the prototype phase. Finally, health worker perceptions were obtained without experience using

ALRITE in clinical practice. This understanding of feasibility in clinical care will be a major focus of future work.

Next steps include updating ALRITE based on user feedback and field testing with frontline health workers. We will also address important potential barriers for implementation, including engaging caregivers, streamlining the ALRITE app to limit any negative effect on existing workflow, developing training programs, ensuring readily available technical support, and engaging key stakeholders at the Uganda Ministry of Health and district health leadership to support further research, medication supply, and ultimate implementation of ALRITE.

CONCLUSION

Taken together, these results provide a detailed, on-the-ground assessment of the opportunities and challenges in the respiratory assessment, diagnosis and treatment of ALRI in young children. Further, the engagement of health workers and richness of data collected support the use of human-centered approaches early-on to identify factors that are pivotal to success of a mHealth application. Finally, our results support the continued development of tailored mHealth tools for decision support in LMICs based on high user acceptability and usability.

Data availability

Data supporting the findings are available within the manuscript. Additional quotes are available upon reasonable request to the corresponding author.

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Author contributions

LEE, MR, JWS, AV, RA, and RN contributed to the concept and study design. AJK developed the mobile health application with mentorship from AV and RA. LEE, IN, and RN coordinated and supervised data collection from the sites. LEE, MR, SAF, IN, BN, and ZN performed data collection. LEE, SAF, and IN analyzed the data, and all authors contributed to interpretation. LEE wrote the draft of the manuscript. RN provided oversight of the project. All authors worked collaboratively to review, edit, and approve the final manuscript.

Competing interests

The authors report no competing interests.

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Figure 1. ALRITE sample screenshots. A) Menu screen. B) Respiratory rate counter. C) Example of diagnosis and treatment recommendations. D) Educational toolkit pop-up on bronchodilator administration. E) Educational toolkit pop-up on stridor.

Figure 2. Frontline health workers' perspectives of determinants of ALRITE implementation.

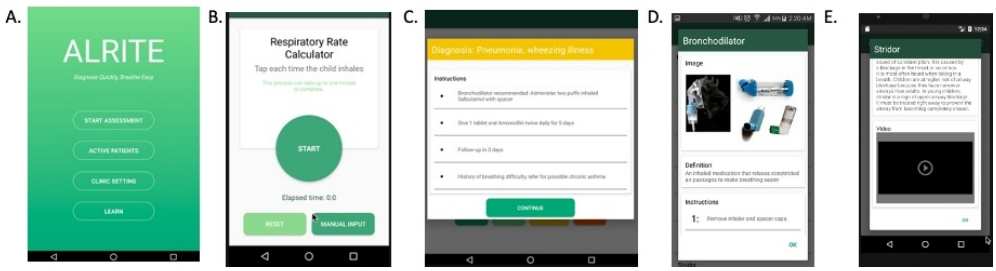

Figure 1. ALRITE sample screenshots. A) Menu screen. B) Respiratory rate counter. C) Example of diagnosis and treatment recommendations. D) Educational toolkit pop-up on bronchodilator administration. E) Educational toolkit pop-up on stridor.

325x87mm (72 x 72 DPI)

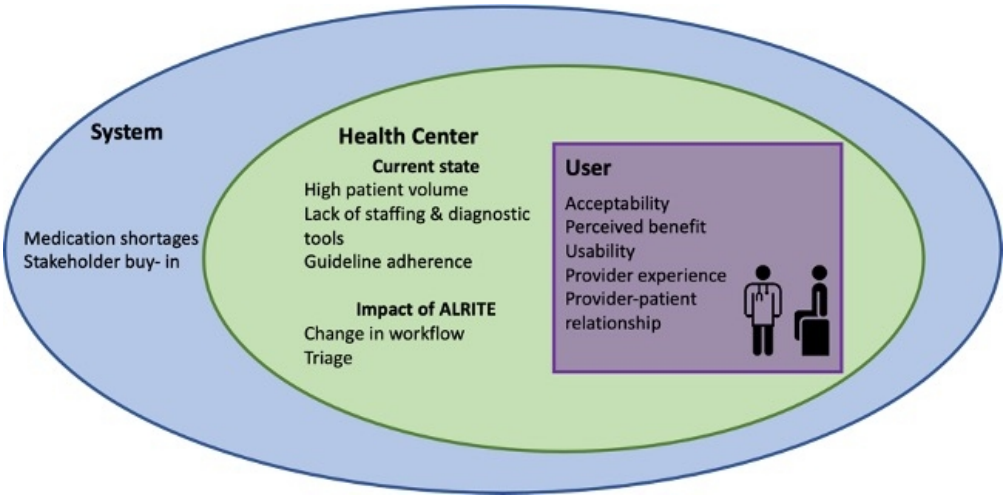

Figure 2. Frontline health workers' perspectives of determinants of ALRITE implementation.

228x112mm (72 x 72 DPI)

In-depth Interviews: Facilitator's Guide

I. Basic information

Tell me about your health center:

- how busy
- proportion of children you see vs adults
- common problems that children come with
- use of WHO IMCI routinely
- when thinking specifically about respiratory disease in children,
  - what is the range of severity?
  - Diagnostic tools available?
  - Treatment?
  - Diagnoses?
  - Referral to hospital? Referrals to specialty care?
  - How comfortable are providers in assessing and treating children?
  - What kind of training do they receive? Is there any refresher training or CME?
  - What are the biggest challenges at your health center in diagnosing and treating children with respiratory illness?
  - how common do you think asthma/recurrent wheezing is in the young children that you see?
  - Which asthma medicines do you commonly use in this health facility? Availability of asthma medications both in the clinic and to take home?

II. Brief demonstration of ALRITE

This app is 27 Mb. Do you think providers would be willing/interested in downloading to their personal device?

Start with brief demonstration, then give time to use the app.

III. General comments – ALRITE tool as mobile app (spend less time here)

- What did you like about the app?
- What did you think could be improved?
- How could this app help fill a need in your health center? What parts of the app could be the most helpful?
- Where do you see challenges with using the app?

IV. Feasibility of ALRITE tool

1) Bronchodilator timing and reevaluation.

- Tell me about use of bronchodilators in this clinic. Are they often prescribed? How are they given (oral/inhaler/nebulizer)? How are they supplied to the clinic? How are they supplied to the patient?
- This tool requires reassessment if a bronchodilator is given to evaluate whether it was helpful or not. How is that different from current practice? Is reassessment usually done?
  - What are barriers not to reassess?

2) Integration into clinical practice

- How can we avoid extra work that may be caused by using the app?

- Biggest challenges/barriers to use?
- What kind of training is required to use the app successfully?
- Interest in using stored information in the app as a form of electronic medical record?

If there's time (and hasn't been addressed during the interview)…

What is the supply chain like for bronchodilators and other medications? Are there some that are always reliably available vs others?

Limitations/challenges that you see regarding resource availability? If so, what specifically?

Challenges with diagnosis of asthma

- can patients access inhaled bronchodilator, spacers if they were helpful
- how often do you refer for specialty care; for what indications; level of respiratory support
- how common do you think asthma/recurrent wheezing is in the young children that you see
- Is there a stigma associated around the diagnosis of asthma?
- Availability of asthma medications both in the clinic and outpatient. Pharmacy – how often dispensed.

What supply is like in pharmacy. How often prescribed by clinicians?

- workflow of a patient from start to finish
- Limitations/challenges that you see regarding resource availability? If so, what specifically?

Focus Group: Facilitator's Guide

I. Brief demonstration of ALRITE (5 min)

This app is 27 Mb. Would you be willing/interested in downloading?

Outline for focus group

1. Information about your health center
2. Feedback on ALRITE app
3. Feasibility of using app within health setting

II. Basic information

Please raise hand if:

a. you own a mobile phone
b. that mobile phone is a smart phone
c. you regularly use applications on your phone (ex: Facebook, Whatsapp, games…)
d. you have used a mobile health application
e. you have completed the WHO IMCI training

(count and record for each)

Ice breaking questions (choose 1 or 2)

- how often do you see kids compared to adults in your setting?
- What is the typical workflow of children coming into clinic with respiratory complaints? *(how patients move from arrival to discharge and treatment)*
- What are the most common diagnoses that you give to children who come to clinic with respiratory symptoms?
- what kind of equipment and treatments do you have to take care of children with respiratory disease?

III. General comments – ALRITE tool as mobile app (25 min)

- What are your general thoughts about the app?
- What did you think could be improved?
- Is there anything that you would remove from the app? Or add?
- Would this be something you would prefer to have on your personal phone or keep on a hospital phone/tablet?
- How could this app help fill a need in your clinical setting?
- Where do you see challenges with using the app?

IV. Feasibility of ALRITE tool (20 min)

3) Bronchodilator timing and reevaluation.

- Tell us about your experience treating children with inhaled bronchodilators.
- The ALRITE app asks to reassess children after receiving a bronchodilator after 10 minutes. If you give bronchodilators to children, do you typically reassess them afterwards? Tell more about it. What are the challenges to perform a reassessment?

4) Integration into clinical practice

- How do you think using this app would change your workload?

- Do you think this app will change the flow of patients that you described earlier? Please elaborate.
- Biggest challenges/barriers to use?

V. IMCI decision tree & Respiratory assessment (if there is time)

- How does this protocol/decision tree follow how you currently assess patients in your clinic?
- Do you think the application impacts your ability to perform respiratory assessment? If so, how? If not, what would make it more useful?

Closing comments

Introduction to ALRITE & Usability test

Description of ALRITE

ALRITE is a mobile health application that was created to help diagnose and manage acute respiratory illnesses in young children. The goal of the app is to provide decision support to healthcare providers for children with acute respiratory complaints. The app contains a decision tree based on the World Health Organization's (WHO) Integrated Management of Childhood Illness (IMCI) case management guidelines.

One unique addition is that ALRITE will guide you through a respiratory assessment to help decide on whether a bronchodilator trial may be beneficial. Globally, wheezing illnesses are under-recognized and could contribute to severe respiratory illness in young children.

After the assessment, ALRITE will provide most likely diagnoses and treatment recommendations based on the information provided: 1) pneumonia, 2) pneumonia + wheezing illness, 3) severe disease requiring urgent referral/intervention, or 4) upper respiratory infection (supportive care only).

Instructions to participant:

We will ask you to complete a series of tasks using simulated clinical scenarios. There is no time limit or one single solution to completing each task. The study is designed to test the app and not you. You are welcome to ask me any questions that you have while completing the task. There may be times in the study where I do not answer your question because we are interested in seeing how you solve the problem. I will let you know when I cannot answer your question.

As you complete these tasks, we are going to ask you to think aloud as you work. Thinking aloud will help provide us an idea of what you are thinking as you are completing the task. We understand that you may forget to think aloud. If this happens, we ask you to tell us what you are thinking about. After each task is completed, I will ask you a few questions about the task. After all tasks have been completed, I will ask you a few questions about your overall experience of the ALRITE mobile application. If any of the questions are unclear, please ask for clarification.

We ask that during the scenarios, you imagine that you are using the app in the middle of a busy clinical shift and answer the questions as such.

Participant Comments & Feedback

Participant comments are verbal cues that indicate successes and failures in the app. We will record these comments digitally for later review as well as notetaking during the interview. Participants will be asked to answer a brief survey after completing the interview.

Errors

Errors are mistakes that the participants make while using the app that slows or stops the participant from completing each task. This data is critical for fixing errors and increasing efficiency in the app. These errors will be documented by the notetaker.

Scenario 1:

Task 1: Input information provided into the app to determine whether a bronchodilator trial is recommended.

A new patient enters your clinic with the following circumstances:

- *Name: (choose your name)*
- *Female*
- *Birthdate (choose a date where the child is between 4-6 months old)*
- *Alert and playful*
- *Not Vomiting or convulsing*
- *No difficulty eating or drinking*
- *Coughing for 10 days*
- *No HIV exposure risk*
- *This is her third episode of coughing/difficulty breathing episode since birth.*
- *On exam, her temperature is 37.3C. Oxygen saturation 94%. Respiratory rate 64. She has moderate chest indrawing. No Stridor. When you listen with a stethoscope, you hear wheezing when she inhales and exhales.*

Task 2: Read aloud whether a bronchodilator trial is recommended. If recommended, please find the tutorial on how to administer the bronchodilator and talk through how to administer to your patient. Input that you have administered the bronchodilator in the app.

Scenario 2:

Task 3: Input information for the respiratory assessment using the video of a child provided.

A new patient enters your clinic with the following circumstances:

- *Name: (choose a friend's name)*
- *Male*
- *Birthdate (choose a date where the child is 3 years old)*
- *Alert and playful*
- *Not Vomiting or convulsing*
- *No difficulty eating or drinking*
- *Coughing for 7 days*
- *No HIV exposure risk*
- *This is his second episode of coughing/difficulty breathing episode since birth*

Watch video and record respiratory assessment

Task 4: Read aloud whether a bronchodilator trial is recommended. Then close the encounter and return to the home screen.

Scenario 3:

Task 5: Return to your first patient's encounter (Scenario 1). Is she ready for re-assessment? How do you know?

If ready, please input her follow up examination outlined below.

- *Name: (your name)*
- *After the bronchodilator, she seems to be breathing a little easier than before the trial. On exam, her oxygen saturation 95%. Respiratory rate 54. She has mild chest indrawing. She still has wheezing but only when she exhales.*

Task 6: Talk through the diagnosis and treatment recommendations provided by the app.

Reporting checklist for qualitative study.

Based on the SRQR guidelines.

		Reporting Item	Page Number
Title			
	#1	Concise description of the nature and topic of the study identifying the study as qualitative or indicating the approach (e.g. ethnography, grounded theory) or data collection methods (e.g. interview, focus group) is recommended	1
Abstract			
	#2	Summary of the key elements of the study using the abstract format of the intended publication; typically includes background, purpose, methods, results and conclusions	2
Introduction			
Problem formulation	#3	Description and signifcance of the problem / phenomenon studied: review of relevant theory and empirical work; problem statement	4-5
Purpose or research question	#4	Purpose of the study and specific objectives or questions	5
Methods			
Qualitative approach and research paradigm	#5	Qualitative approach (e.g. ethnography, grounded theory, case study, phenomenolgy, narrative research) and guiding theory if appropriate; identifying the research paradigm (e.g. postpositivist, constructivist / interpretivist) is also recommended; rationale. The rationale should briefly discuss the justification for choosing that theory, approach, method or technique rather than other options available; the assumptions and limitations implicit in those choices and how those choices influence study conclusions and	8

		transferability. As appropriate the rationale for several items might be discussed together.	
Researcher characteristics and reflexivity	#6	Researchers' characteristics that may influence the research, including personal attributes, qualifications / experience, relationship with participants, assumptions and / or presuppositions; potential or actual interaction between researchers' characteristics and the research questions, approach, methods, results and / or transferability	7-8
Context	#7	Setting / site and salient contextual factors; rationale	5-6
Sampling strategy	#8	How and why research participants, documents, or events were selected; criteria for deciding when no further sampling was necessary (e.g. sampling saturation); rationale	6,8
Ethical issues pertaining to human subjects	#9	Documentation of approval by an appropriate ethics review board and participant consent, or explanation for lack thereof; other confidentiality and data security issues	9
Data collection methods	#10	Types of data collected; details of data collection procedures including (as appropriate) start and stop dates of data collection and analysis, iterative process, triangulation of sources / methods, and modification of procedures in response to evolving study findings; rationale	7-9
Data collection instruments and technologies	#11	Description of instruments (e.g. interview guides, questionnaires) and devices (e.g. audio recorders) used for data collection; if / how the instruments(s) changed over the course of the study	7, supplement
Units of study	#12	Number and relevant characteristics of participants, documents, or events included in the study; level of participation (could be reported in results)	9
Data processing	#13	Methods for processing data prior to and during analysis, including transcription, data entry, data management and security, verification of data integrity, data coding, and anonymisation / deidentification of excerpts	7
Data analysis	#14	Process by which inferences, themes, etc. were identified and developed, including the researchers involved in data analysis; usually references a specific paradigm or approach; rationale	8

Techniques to enhance trustworthiness	#15	Techniques to enhance trustworthiness and credibility of data analysis (e.g. member checking, audit trail, triangulation); rationale	8
Results/findings			
Syntheses and interpretation	#16	Main findings (e.g. interpretations, inferences, and themes); might include development of a theory or model, or integration with prior research or theory	9-19
Links to empirical data	#17	Evidence (e.g. quotes, field notes, text excerpts, photographs) to substantiate analytic findings	10-19
Discussion			
Intergration with prior work, implications, transferability and contribution(s) to the field	#18	Short summary of main findings; explanation of how findings and conclusions connect to, support, elaborate on, or challenge conclusions of earlier scholarship; discussion of scope of application / generalizability; identification of unique contributions(s) to scholarship in a discipline or field	20-22
Limitations	#19	Trustworthiness and limitations of findings	22
Other			
Conflicts of interest	#20	Potential sources of influence of perceived influence on study conduct and conclusions; how these were managed	24
Funding	#21	Sources of funding and other support; role of funders in data collection, interpretation and reporting	24

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Health workers' perspectives of a mobile health tool to improve diagnosis and management of pediatric acute respiratory illnesses in Uganda: A qualitative study

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Abstract

Objectives: Mobile health tools have potential to improve the diagnosis and management of acute lower respiratory illnesses (ALRI), a leading cause of pediatric mortality worldwide. The objectives were to evaluate health workers' perceptions of acceptability, usability, and feasibility of ALRITE, a novel mobile health tool to help frontline health workers diagnose, treat and provide education about ALRI in children <5 years.

Design: A qualitative study including semi-structured interviews with health facility administrators and focus groups with primary care health workers.

Setting: Two federally funded Ugandan primary care health facilities, one peri-urban and one rural.

Participants: We enrolled 3 health administrators and 28 health workers (clinical officers and nurses).

Intervention: The ALRITE smartphone application was developed to help frontline health workers adhere to ALRI guidelines and differentiate wheezing illnesses from pneumonia in children under 5 years of age. ALRITE contains a simple decision tree, a partially automated respiratory rate counter, educational videos, and an adapted respiratory assessment score to determine bronchodilator responsiveness. We performed a demonstration of ALRITE for participants at the beginning of interviews and focus groups. No participant had used ALRITE prior.

Results: Themes impacting the potential implementation of ALRITE were organized using individual-level, clinic-level, and health-system level determinants. Individual-level determinants were acceptability and perceived benefit, usability, provider needs, and provider-patient relationship. Clinic-level determinants were limited resources and integration within the health center. Systems-level determinants included medication shortages and stakeholder engagement.

Conclusions: Incorporation of these themes will ready ALRITE for field testing. Early engagement of end-users provides insights critical to the development of tailored mHealth decision support tools.

Strengths and limitations of this study

- By using a technology probe and human-centered participatory approach early in mHealth development, we engaged participants and gathered information not only about the ALRITE tool but also contextual factors that are pivotal to the ultimate success of a mHealth application in this setting
- We partnered with local health officials in the planning phase to encourage health worker attendance to information sessions, which translated to enrolling almost all eligible health workers, thus providing a more accurate and complete assessment at each study site
- This study was limited by perspectives at two health centers, which may not reflect regional differences in resource availability, staffing, and health workers' perceptions.
- Health worker perceptions were obtained without experience using ALRITE in clinical practice, which will be a focus of future work.
- We acknowledge that key team members who participated in all aspects of this project are American physicians/researchers who bring a different set of experiences and lens to this work, which may have influenced participants' responses and interpretation, but American team members worked in close partnership with Ugandan team members to ensure shared decision-making and engagement with study participants.

Keywords: Community child Health, international health services, paediatric thoracic medicine, respiratory infections, qualitative research, public health, mobile health

INTRODUCTION

Acute lower respiratory illnesses (ALRI) remain a leading cause of mortality in children under 5, responsible for 15% of all deaths in this age range.[1 2] Over 800,000 young children worldwide die of ALRI each year; 500,000 of these deaths occur in sub-Saharan Africa.[1-5] In Uganda, ALRI is responsible for 11% deaths in children under 5.[5 6] ALRI encompass multiple disease processes that include bacterial pneumonia, viral pneumonia, and wheezing illnesses. Differentiating between these diseases and choosing the appropriate treatment plan is challenging, especially where skilled personnel and diagnostic tools are lacking. The World Health Organization (WHO) Integrated Management of Childhood Illnesses (IMCI) provides guidelines for ALRI diagnosis and management, with emphasis on pneumonia and treatment with antibiotics. The IMCI was updated in 2014 to include assessment of wheezing and treatment with inhaled bronchodilators,[7] but wheezing illness remains underdiagnosed and undertreated in low- and middle-income countries (LMICs).[8,9]

Mobile phone use recently surpassed two-thirds of the global population and over 70% in Uganda[10], offering opportunities for digital health tools to enhance adherence to guidelines and build capacity through clinician education.[11-16] Importantly, small pilot studies of mHealth tools based on WHO IMCI ALRI guidelines demonstrated promising preliminary results but have not addressed wheezing illness.[17-20] To promote responsible, sustainable, and high impact mHealth interventions in LMICs, the WHO recently released digital health guidelines recommending high quality research in fields of decision support and education.[21]

We developed the Acute Lower Respiratory Illness Treatment and Evaluation (ALRITE) mHealth application as a decision support tool to aid frontline health workers to improve diagnosis and treatment of ALRI in children under 5 years of age, with a particular focus on distinguishing wheezing illness from pneumonia. In order to address potential challenges with

widespread ALRITE use, this study sought to understand determinants of successful ALRITE implementation from the end users' perspective. The objective of this study was to evaluate health workers' perceptions of feasibility, usability, and acceptability of the ALRITE mHealth tool in two Ugandan primary care health centers. This user-centered, formative approach will inform further development of a locally relevant decision support tool to improve the diagnosis and treatment of ALRI in Ugandan health centers.

METHODS

Study design

This study uses a human-centered, or participatory, approach to examine frontline health workers' perceptions of ALRITE and its impact on their workflows and patient care. We developed an initial prototype of ALRITE and used it as a technology probe to gather insights about its feasibility, usability, and acceptability. Technology probes are defined as instruments to "[collect] information about the use and users of the technology in a real-world setting", improve the intervention's design by meeting the needs and wishes of the user, and field-test.[22] We used an exploratory qualitative study design to allow for deeper exploration into feasibility, usability, and acceptability for the purposes of 1) improving the mHealth tool, 2) identifying barriers/facilitators beyond the tool itself to inform feasibility and implementation strategies, and 3) determining quantitative outcomes measures for future studies (qual to QUAN mixed methods approach).[23] The research team determined that quantitative survey data would have been inadequate to answer our research questions due to lack of depth, opportunity to probe, and concerns about social desirability bias.

We conducted in-depth semi-structured interviews with health facility administrators to understand clinic context, availability of resources, challenges, day-to-day operations, and feasibility of ALRITE from a systems standpoint (Supplementary Material). We conducted focus

groups with primary care health workers (clinical officers and nurses) to understand how participants respond to peer responses and the forces that may influence their thinking and behavior around the app, how this would affect patient-provider interactions, and their reactions towards technology. All health worker participants had time to practice using ALRITE with clinical scenarios (Supplementary Material) before focus groups to give participants a better understanding of the app, its content, and usability to better inform their focus group responses.

Study sites

Both study sites were federally funded Health Center IV in Jinja district, Uganda and offer free healthcare. The peri-urban site is located 15 minutes driving from the city center of Jinja, the second largest city in Uganda, and the rural site is located 45-60 minutes driving from Jinja. Both sites have inpatient and outpatient facilities and an operating theater for obstetrics and urgent surgical cases.

The health care delivery system in Uganda has 6 levels that build on the previous level: 1) Health Center II provides basic outpatient care; 2) Health Center III has maternity services; 3) Health Center IV has primary care, basic inpatient facilities and emergency obstetric care; 4) District Hospitals have general surgery, dental services, and diagnostic services (i.e. chest radiography and laboratory); 5) Regional Referral Hospitals have specialized care; 6) National Referral Hospital has additional specialized and sub-specialized services.

The two specific Health Center IV were selected for this study based on prior research indicating that 1) adherence to IMCI was low, 2) consultations were performed by health workers with limited training, 3) antibiotics were over-prescribed, and 4) inhaled bronchodilators for wheezing illness were not prescribed.[9]

Participants

We recruited at least 1 health administrator for semi-structured interviews from each study site. Health administrators were clinicians (medical doctors or clinical officers) who serve a director role in leadership and staff supervision at an individual health center, termed locally as “health facility in-charges”. Eligible participants for focus groups were health workers (clinical officers or nurses) who had been working at the study site for at least 6 months and were responsible for outpatient care of children. None had used ALRITE prior. Clinical officers complete a three-year diploma course in clinical medicine. Nurses in these health centers primarily act as clinicians due to staff shortages and task shifting. Prior to data collection, research team members met with officials at the Jinja District Health Office for approval, plan for disseminating study information to participating study sites, and scheduling days for recruitment and data collection. Information sessions were coordinated with help from health administrators at each study site to maximize participation. All health workers were notified about the session dates one week in advance and were invited to attend the information session even if not scheduled to work that day. The study team employed in-person information sessions for recruitment using convenience sampling. Sample size was determined by the number of health workers who showed up the scheduled days of data collection with the goal of recruiting all eligible health workers at each study site. All participants provided a written informed consent in English for their participation.

ALRITE mHealth tool

Based on a previous mHealth tool, mPneumonia[17 18], the ALRITE mHealth application was developed for smartphones to help frontline health workers adhere to IMCI guidelines and differentiate wheezing illnesses from pneumonia in children under 5 years of age. ALRITE contains a simple decision tree, a partially automated respiratory rate counter, educational videos (brief clips providing examples of children in respiratory distress, taken from WHO IMCI

training videos with permission), and an adapted respiratory assessment score to determine bronchodilator responsiveness (Figure 1). The algorithm walks the user through basic demographics, IMCI danger signs, medical history, physical exam, and bronchodilator assessment (if appropriate). The final diagnoses include *severe pneumonia or very severe disease, pneumonia +/-, wheezing illness, and cough or cold +/- wheezing illness.* The WHO classification does not include a separate diagnosis of "wheezing illness" but rather includes the diagnosis and treatment of wheezing as additional recommendations for the diagnoses of "pneumonia" and "cough or cold". [7] We added the term "wheezing illness" to ALRITE diagnoses to prompt health workers to provide bronchodilators and refer for further assessment as necessary. The app is 27 MB and was downloaded on supplied Android smartphones for study use.

Data collection and management

Prior to data collection, research assistants were trained and pretested focus group/interview guides through simulations with the research team. Demographic information was collected first on paper forms, then transferred to REDCap (Research Electronic Data Capture).[24] Unique identifiers were used for each participant. Focus groups and interviews were performed primarily in English over the course of one week using interview/focus group guides (Supplementary information). Prior to focus groups, all health worker participants were given time to practice using ALRITE by going through at least 2 clinical scenarios individually or in small groups of up to 3 people (Supplementary information), while members of the study team (LEE, IN, MR, SAF, BN, ZN) asked for specific feedback, answered questions about the app, and took notes. We performed a demonstration of ALRITE for participants at the beginning of interviews and focus groups. Ugandan research assistants did provide clarifications and some probing in the local language; some participant responses were given in the local language and translated to English for the study notes. All interviews and focus groups were digitally recorded,

deidentified, and transcribed into English without identifiers by IN, who is fluent in English and the local language. Transcriptions were reviewed by IN and LEE for content and cultural accuracy. Members of the study team (LEE, IN, MR, SAF) took notes during focus groups and interviews to augment and clarify the transcribed notes. Hard copy data were securely transported to Makerere University Lung Institute (Kampala, Uganda) for secure storage. No personal data will be transferred from the primary institution in Kampala, Uganda.

Study team

This was an international collaboration, including experts in public health, pulmonology/asthma, information and communication technology for development, human-computer interaction, and community-based interventions. Research assistants BN and ZN from Uganda experienced in qualitative interviewing and fluent in the local language led focus groups and interviews with the guidance of LEE, a content expert in the ALRITE app with previous qualitative experience in technology implementation. SAF provided qualitative expertise in design, data collection, and analysis. RN provided local expertise in health systems, qualitative design and interview guides, and pediatrics. IN provided local research coordination and knowledge of the health system. Pediatric expertise was provided by RN and JS with additional pediatric pulmonology expertise by MR and LEE. RA was instrumental in the design of mPneumonia and senior author on both manuscripts.[17 18] ALRITE app design and development was performed by AK, AV, and RA, with additional expertise in usability testing and human-centered design by AV. We acknowledge that key team members who participated in all aspects of this project are American physicians and researchers who bring a different set of experiences and lens to this work, and that our positionality may have influenced participants' responses and interpretation. Working in partnership with our Ugandan team was critical to ensure shared decision-making and our ability to work closely with the clinicians.

Analysis

We analyzed our detailed notes and transcripts using a deductive thematic approach, whereby the researchers LEE, SAF, and IN examined the data to identify common themes for each of the research questions based on a similar framework of a previously published mHealth technology.[17 18] During the analysis, the team documented outlier or dissenting perspectives in order to provide a more complete picture of participant responses to ALRITE. First, LEE and SAF read through each of the transcripts and set of notes and then we developed a provisional framework based on primary research questions. LEE, SAF, MR, IN, BN, and ZN held team meetings following each day of data collection to compile notes, review emerging themes, and refine the coding framework. Codes were aggregated into major themes and subthemes by first annotating an online document of transcripts, then reorganizing into a separate document, similar to but without the use of coding software. Additional meetings with the research team allowed for further refinement of themes and subthemes. Transcripts were reread to ensure that preliminary results represented the majority of user feedback. The quotes were chosen to confirm and highlight themes and introduce diverging viewpoints not previously captured. The Standards for Reporting Qualitative Research (SRQR) were used to guide reporting.[25]

Ethics

The study was approved by the Mulago Hospital Research and Ethics Committee and Uganda National Council for Science and Technology (HS2692). The study was reviewed and received exempt status from the University of Washington (STUDY0007895). Written informed consent was obtained from all participants in accordance with international and local regulations.

Patient and Public involvement

While not involved in the initial design, conduct, or reporting, study participants are involved in ultimate design and implementation of the intervention and are included in the dissemination plan, along with district- and national-level health system members and patient caregivers.

RESULTS

Participant & setting characteristics

In January 2020, we enrolled 28 healthcare provider participants across 2 health centers in Uganda. Key stakeholders, including 3 health administrators (HA), took part in individual in-depth interviews, while 5 clinical officers and 20 nurses (HW) took part in 3 focus groups (Table 1). Based on recommendations from the health administrators from each site, we conducted separate focus groups for clinical officers (n=3) and nurses (n=10) at the peri-urban site to limit concerns around potential unequal power dynamics, but this was not deemed a concern at the rural site where one focus group was recommended. Interviews were approximately 30 minutes long, while focus groups were approximately 1.5 hours in length.

Table 1. Participant characteristics

	Rural Site	Peri-urban Site
In-depth interviews	**n=1**	**n=2**
Role		
Medical officer	0	2
Clinical officer	1	0
Male	1	2
Focus groups	***n=12***	***n=13***
Role		
Clinical officer	2	3
Nurse	10	10
Female	9	10
Age		
<30 years	5	5
30-40 years	5	6
>40 years	2	2
Experience in health care, years		
< 5	2	3
5-10	8	4
> 10	2	6

We identified several themes impacting the development and implementation of ALRITE in Ugandan health centers from the perspective of health administrators and frontline health workers. Themes were organized by a social ecological model of determinants: individual, clinic, and health system (Figure 2). Individual-level determinants were acceptability and perceived benefit, usability, provider needs, and provider-patient relationship. Clinic-level determinants were limited resources, integration within the health center. Systems-level determinants included medication shortages and stakeholder engagement. Each theme is presented below in greater detail and with direct quotes that typify respondent comments.

Individual-level

Acceptability & perceived benefit of ALRITE

All health workers indicated they would like to have ALRITE available to use in their healthcare setting. Health workers also reported that they appreciated that ALRITE reminded them of important medical questions to ask and key components of the physical exam.

> "It helps us to remember the clear assessment of these children because at times you are rushing and forget to assess something. You go with what you see quickly, but the app gives you the procedure to follow. It also helps in giving the right doses." HW-002-FG2

They responded positively to the integrated respiratory rate counter. Health workers' eagerness to learn was apparent during focus groups and interviews. Indeed, many health workers reported the educational videos were one of their favorite features of ALRITE. In addition to data gathering, health workers liked the information management capabilities, including medication dosing, which is generally age- or weight-based for children.

> "The part of the app that I like mainly are the videos. It is good because it helps diagnosing and guides through the right treatment hence saving patient time." HA-001

> "[The respiratory rate counter] is convenient because you may not have a watch." HW-007-FG3.

It is important to acknowledge the novelty of ALRITE as a mHealth app technology likely contributed to high acceptability by health workers as well.

> "[Providers] usually like new technology, I think they will be excited to use it and therefore they are likely to download [the app]. In addition, people prefer digital information than opening and reading what is in the [IMCI] book." HA-003

Respondents had ideas for improving acceptability, appropriateness, and potential benefit of ALRITE. Health workers asked for additional automated or semi-automated smartphone tools, such as pulse oximetry or digital auscultation to be integrated into ALRITE. Multiple health workers commented on the potential for storage of clinical information. One health worker wanted to use it as a personal quality control device to review his previous diagnoses and treatment plans. A few wanted the app expanded to other disease processes and age groups. Some health workers suggested incorporating additional educational components targeted to patients and families. One health worker suggested incorporating risk stratification for children with chronic disease and environmental risk factors (i.e. smoke exposure, crowded housing) in order to focus on prevention.

> "[In the app], we are missing [a question on] the type of fuel used at home to cook and source of light. Some produce a lot of smoke. [By offering recommendations, families] can change the way of cooking, hence reducing exposures. This could help in prevention [of respiratory diseases]. We therefore can make a recommendation and follow up in about 6 months." HW-005-FG3

ALRITE usability

We defined usability as "the design factors that affect the user experience of operating the application's device and navigating the application for its intended purpose."[18] ALRITE features that contributed to a positive user experience included overall design, simplicity, flow, and clarity of diagnosis. Generally, health workers thought the app was easy to follow and would be quick to get to diagnosis.

> "It saves time. You diagnose very fast and you are able to know the treatment to give so it improves on the appropriate management of patients." HW-001-FG1

When given the opportunity to use the mHealth tool, health workers who owned smartphones were more facile with ALRITE than those who owned simple mobile phones. Importantly, after practicing with ALRITE and receiving coaching from the research team, all health workers became more facile using ALRITE. Proficiency with the app was not formally tested.

Health workers provided valuable feedback to improve the usability of ALRITE, including minor changes to the visual display, layout, and flow of the app. For example, health workers recommended larger font for better visualization. They also recommended using a patient age group instead of date of birth for 2 reasons: 1) health workers had difficulty using the calendar

function, and 2) caregivers may not know a child's date of birth, so asking for a child's age group is standard practice.

Provider-specific needs

Another important consideration to ALRITE acceptability is the end user's experience with smartphones. In our study, all health workers owned a mobile phone, of which approximately 60% owned a smartphone. Most who owned a smartphone used social media or communication apps. No health workers we spoke with were using mHealth apps, and only a few had heard of these types of apps.

All those with smartphones preferred that ALRITE be directly downloaded to their personal devices compared to clinic-supplied devices, as they would be more likely to use the app if it were readily available on their own smartphones. Additionally, if health workers used the app on their own smartphones rather than a clinic-supplied device, they said they would be less likely to lose or misplace the device. However, one health worker reminded the group that not everyone has a smartphone, so smartphones would need to be made available to individuals without a personal device. Health workers were pleased that the size of the app was only (27Mb).

The provider's training level was also an important factor. In different levels of health centers in Uganda, there are health workers with varying levels of training and provider roles, ranging from nurse to medical officer. End users with limited clinical training may be more likely to use ALRITE in practice to help with clinical decision-making than others with more training or clinical experience who may not think additional clinical decision support adds value to their clinical care.

> "There are incidences when the doctors are not at the clinic and the nurse needs to make a diagnosis and give treatment as well. ALRITE will save time." HA-001

Provider-patient relationship

Health workers had some concerns regarding ALRITE use in their clinic. Some thought that using the app in front of patients and families would reduce the quality and quantity of personal interaction at a clinic visit. Some also expressed concern that if they used ALRITE to help make clinical decisions, families would lose trust in health workers' ability to diagnose and treat. However, one respondent also suggested that the app could be used as an educational tool for families and help build trust during the visit.

> "The first challenge is on the side of our clients. When you are busy using the app, the client might think you're neglecting her or him and you're busy on WhatsApp, and secondly, a client might think you're not knowledgeable enough since you're using a phone and lose trust in you thinking you don't know what to do… But I think I can start by engaging the patients and informing them that what I am going to do is for your good, I am not just looking for answers but rather improving diagnosis for your child." HW-003-FG2

Clinic-level

Limited resources

High patient volume and limited staffing

At the peri-urban site, 100-300 patients are seen in the ambulatory clinic daily, 60% of which are children (IC-001). Similarly, at the rural site, a stakeholder reported, "we see about 100-200 patients daily… and about 45% of these are children less than 5 years." (IC-003). Stakeholders identified the most common pediatric conditions: malaria, ALRI, and diarrhea. A combination of

clinical officers and nurses without specialty pediatric training see pediatric patients at both sites. The peri-urban site also staffs a few general medical doctors, but they are not always on site. All health workers reported they received IMCI training, from which Uganda Clinical Guidelines are derived.[26] Health workers reported that visit length typically ranges from 10-15 minutes, but a few reported they often take less than 10 minutes.

> "In assessing children, we have a challenge with patient load with few trained health workers who can assess patients. It's a facility in a semi-urban area so the numbers are big with few health workers, and treatment is not always available." HA-001

Limited resources for the diagnosis of pediatric respiratory disease

To diagnose respiratory disease, both sites reported use of stethoscopes, although these are not universally available, nor are they required to use IMCI. They rely on personal watches to count respiratory rate, but not everyone has a watch. Pulse oximetry is not typically available.

> "We have one pulse oximeter in [the operating] theater, but we are currently not using it because it gives confusing results." HA-003

> "It is not a problem [to use a stethoscope], but if it is not available, we resort to the IMCI approach where you depend on a physical exam [without a stethoscope]. In addition, what compromises quality is the number of patients waiting in the line to be reviewed, and you may end up missing out on an important indicator." HW-002-FG3

Limited resources and training affecting adherence to WHO IMCI

All health workers received WHO IMCI training. However, they reported that adherence to IMCI can be challenging for a number of reasons. Firstly, IMCI incorporates respiratory rate and

evaluation of respiratory distress into its clinical decision algorithm. Some health workers reported that counting respiratory rate is impossible without a watch or timer. Secondly, IMCI recommends evaluation of wheezing, but this exam finding is challenging to diagnose, especially without a stethoscope.

> "[Chest] indrawing is easier [to assess] compared to wheezing." HW-001-FG3

> "Monitoring during the care of these children or reassessing the vitals is a challenge." HW-003-FG3

Health workers frequently denied opportunities for robust continuing medical education or refresher trainings for IMCI.

> "We have sent people for IMCI training. We also have a national trainer at the facility who organizes [continuous medical education], but the turnout of health workers is usually not good. Usually, when people do something for many years, they tend to think there is nothing new they can learn." HA-003

Thirdly, availability and use of the IMCI materials are limited in health centers. IMCI can be available in paper or electronic form. However, health workers reported that the paper form is not convenient to use due to the size of the booklet and the likelihood of misplacing it. One health administrator reported that his health center had IMCI installed on a laptop, but the laptop broke and was not replaced.

ALRITE integration into existing health system

Change to workflow

Integrating ALRITE into clinical practice will inevitably change clinic workflow. It may contribute to duplicative work because the current system includes entering data into a written health record. Interestingly, this was not brought up as a concern during focus groups or interviews. Furthermore, using a new technology will be slow at first and may make patient encounters longer rather than shorter in an already busy clinic. Health workers reported that they would need to practice with ALRITE prior to using it with patients to improve work efficiency.

> "At first, it's likely to slow the work because we may be learning the app but with time it will become part of us, and we become part of it so it will ease the work… we need to be familiar with it to help us save time so that patients do not see us take a lot of time on the phones." HW-002-FG2

> "I think we shall have to sort out those with respiratory illnesses at triage which is different from what is being done currently where all patients follow the same assessment route regardless of condition." HW-001-FG1

Furthermore, current practice in Ugandan health centers does not routinely include reassessment of patients after a bronchodilator trial, which is necessary to ascertain whether patients would benefit from treatment with a bronchodilator. Most health workers thought it would be feasible to reassess patients if warranted; however, a few health workers reported that many patients leave after the initial assessment. Lack of reassessment would limit providers' ability to determine bronchodilator responsiveness, an important factor in diagnosing wheezing illnesses and asthma in young children and therefore an important component of ALRITE.

> "We reassess only those who are admitted on the wards. We reassess if the child worsens, but if they are improving, we reassess them the next day during the ward

rounds. I think it's important to integrate the app into the system because it gives reminders about reassessing a patient." HA-001

"There is no opportunity [to reassess children] because most of them come from far and do not usually come back [after treatment is prescribed]." HW-001-FG3

Triage

One current challenge and potential opportunity for ALRITE integration is in patient triage. Health administrators reported no formal triage process to risk-stratify patients as they present to care. There is also no separate pediatric clinic. All patients are seen in the order they arrive, whether adults or children. One health administrator saw ALRITE implementation as an opportunity to establish triage at their health center. He suggested that ALRITE could be used earlier when pediatric patients arrive to the clinic to prioritize those with WHO danger signs and acute respiratory distress.

"[Challenges include] lack of a dedicated clinician to manage children and lack of enough consultation rooms. There is also a knowledge gap in assessing children. We do not have a triage area where we are able to prioritize those with worse conditions. We usually just do visual observation of who is an emergency situation instead of taking medical history and a few vitals. The other issue is we don't differentiate children from adults, they all go through the same entry point… The other [issue] is lack of an emergency unit for children with severe difficulty in breathing." HA-003

Systems-level

Medication shortages impacting ALRITE management

Aside from features of ALRITE itself, we explored other factors that would impact feasibility of ALRITE at a systems level. ALRITE recommends treatment for children with respiratory illnesses, including antibiotics for pneumonia and inhaled bronchodilators with/without systemic corticosteroids for wheezing. Oral salbutamol is generally available at the health centers and sometimes used for children but carries a high side effect profile and is not recommended for acute wheezing in children.[27 28] Health administrator at both sites reported very limited availability of inhaled bronchodilators (2-3 inhalers every 2 months). Health workers may prescribe medications if not available on site, but this requires family members to pay out-of-pocket for prescribed medications at an off-site pharmacy or higher-level health center. Even if ALRITE improves diagnosis of wheezing illness, its impact and feasibility will be greatly limited if appropriate treatment is not readily available.

> "We are not independent when it comes to drugs. Supplies are from National Medical Stores, and they usually give what they have unless you have an independent source outside of the usual supply chain." HA-002

> "The app talks about the bronchodilator, but it doesn't talk about other drugs to give. Here at the low-level facilities we do not have the bronchodilators." HW-002-FG1

Stakeholder buy-in

While not a common theme, one health administrator emphasized the importance of engaging stakeholders early for successful implementation. Specifically, the administrator explained that the Ministry of Health in Uganda and local district health officials would need to approve the app prior to large scale distribution across public and private facilities. Additionally, support at these leadership levels will be critical for widespread uptake and implementation of ALRITE.

DISCUSSION

In this study, we identified key determinants towards successful implementation of ALRITE, our mHealth decision support tool, from frontline health workers' perspectives (Figure 2). In addition to ALRITE-specific determinants, health workers and administrators identified important individual-level, clinic-level, and health systems-level determinants and offered innovative ideas for future app development. Overall, these results support ongoing development of ALRITE for potential integration into routine clinical care and underscore the importance of user-centered design early in development prior to implementation of a new technology. ALRITE, if successfully implemented, has the potential to improve childhood morbidity and mortality in three major ways: 1) increased awareness, diagnosis and treatment of wheezing illness, 2) improved IMCI guideline adherence through prompts and education, and 3) effective triage of critically ill infants and children. Potential challenges identified include changes to the provider-patient relationship, time constraints, and medication shortages. However, through thoughtful design and implementation, ALRITE has potential to overcome these challenges by enhancing the provider-patient relationship through education and improved management, improving clinical efficiency through a streamlined process, and increasing supply of life-saving medications such as inhaled bronchodilators through increased awareness, advocacy, and demand.

Additional strengths of the study include using a technology probe and human-centered, participatory approach early in mHealth development to engage participants and gather information not only about the specific mHealth tool but also to build an underpinning knowledge of factors that are pivotal to the ultimate success of a mHealth application. We partnered with local health officials in the planning phase to encourage health worker attendance to information sessions, which translated in almost all eligible health workers at each site participating in the study to provide a more accurate and complete on-the-ground assessment at each study site.

We also included health administrators as participants to provide a broader understanding of the clinic context, challenges, day-to-day operations, and feasibility of ALRITE from a systems standpoint, adding a unique perspective to the health workers' responses.

Previous studies have also evaluated mHealth decision support based on WHO IMCI.[17-19] The predecessor to ALRITE, mPneumonia, demonstrated high acceptability and usability in pilot studies in Ghana.[17 18] Unlike ALRITE, mPneumonia was designed to use on clinic-supplied tablets. Health workers were not as familiar with smartphones and had difficulty navigating the application and general tablet use.[17] Furthermore, health workers expressed potential challenges of mPneumonia including access to electricity and added time to patient encounters.[18] The disparate results between mPneumonia and ALRITE likely reflects interval improvements in devices and software as well as additional experience with smartphones given growing mobile phone use worldwide.

Two important systematic reviews of health workers' perspectives using mHealth in primary care highlighted similar themes.[21 29] Decision support mHealth tools achieved high acceptability, with health workers reporting increased efficiency, better access to information, and improved adherence to guidelines.[21] Similar to our results, some health workers were concerned mHealth may negatively impact the provider-patient relationship,[21] but this concern has not been evaluated by patients or caregivers. Contrary to our results, some health workers were concerned the algorithm was too prescriptive for clinical decision making.[21] We found that health workers appreciated the simple ALRITE algorithm, which may reflect the limited clinical training in our study population. Additional factors influencing health workers' acceptability of mHealth technologies were cost to the health worker, previous mobile phone experience, and increased time/workload.[29] While our study did not evaluate cost, as ALRITE would be a free application, health workers did appreciate that ALRITE had a small footprint (27 Mb) so would not require

much data or take up much smartphone memory. Conversely, health worker perceptions of ALRITE did not change based on prior mobile phone experience, but those with smartphone experience were much more facile with the app.

There has been a recent explosion of digital health tools for use in LMICs, but evidence on effectiveness and scale-up has been lacking.[11 16 30 31] An early human-centered approach to evaluation is critical to better understand determinants of successful implementation and to guide further mHealth design. Therefore, we included health administrators and frontline health workers early in the development of ALRITE as participants to better inform acceptability, appropriateness, and feasibility of its use in Ugandan health centers. Through stakeholder interviews and health worker focus groups, we not only received important feedback to improve ALRITE, but also gained a richer understanding of the health setting and potential systems-based and individual level challenges to implementation.

This study had important limitations. First, perceptions of health workers were limited to two health facilities in Uganda. We purposefully chose one peri-urban and one rural health center to better understand differences in resource availability, staffing, and health workers' perceptions. However, there may be additional regional differences in perceptions of and comfort with ALRITE that have yet to be explored. Secondly, it may be possible that we did not capture the full breadth of perspectives, as health workers with dissenting opinions may not have felt comfortable speaking up during focus groups. We tried to address this by probing for dissenting opinions during focus groups and while health workers were practicing with the app in smaller groups. Thirdly, we did not perform formal quantitative usability evaluations. A formal evaluation of end user proficiency was not the objective of this study because the ALRITE app was still in the prototype phase. Finally, health worker perceptions were obtained without experience using

ALRITE in clinical practice. This understanding of feasibility in clinical care will be a major focus of future work.

Next steps include updating ALRITE based on user feedback and field testing with frontline health workers. We will also address important potential barriers for implementation, including engaging caregivers, streamlining the ALRITE app to limit any negative effect on existing workflow, developing training programs, ensuring readily available technical support, and engaging key stakeholders at the Uganda Ministry of Health and district health leadership to support further research, medication supply, and ultimate implementation of ALRITE.

CONCLUSION

Taken together, these results provide a detailed, on-the-ground assessment of the opportunities and challenges in the respiratory assessment, diagnosis and treatment of ALRI in young children. Further, the engagement of health workers and richness of data collected support the use of human-centered approaches early-on to identify factors that are pivotal to success of a mHealth application. Finally, our results support the continued development of tailored mHealth tools for decision support in LMICs based on high user acceptability and usability.

Data availability

Data supporting the findings are available within the manuscript. Additional quotes are available upon reasonable request to the corresponding author.

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Author contributions

LEE, MR, JWS, AV, RA, and RN contributed to the concept and study design. AJK developed the mobile health application with mentorship from AV and RA. LEE, IN, and RN coordinated and supervised data collection from the sites. LEE, MR, SAF, IN, BN, and ZN performed data collection. LEE, SAF, and IN analyzed the data, and all authors contributed to interpretation. LEE wrote the draft of the manuscript. RN provided oversight of the project. All authors worked collaboratively to review, edit, and approve the final manuscript.

Competing interests

The authors report no competing interests.

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Figure 1. ALRITE sample screenshots. A) Menu screen. B) Respiratory rate counter. C) Example of diagnosis and treatment recommendations. D) Educational toolkit pop-up on bronchodilator administration. E) Educational toolkit pop-up on stridor.

Figure 2. Frontline health workers' perspectives of determinants of ALRITE implementation.

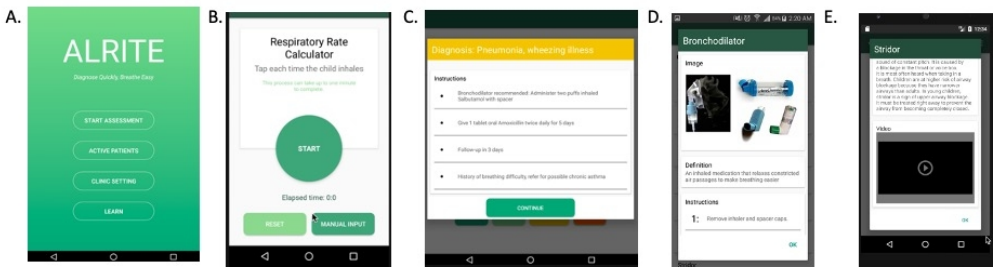

Figure 1. ALRITE sample screenshots. A) Menu screen. B) Respiratory rate counter. C) Example of diagnosis and treatment recommendations. D) Educational toolkit pop-up on bronchodilator administration. E) Educational toolkit pop-up on stridor.

325x87mm (72 x 72 DPI)

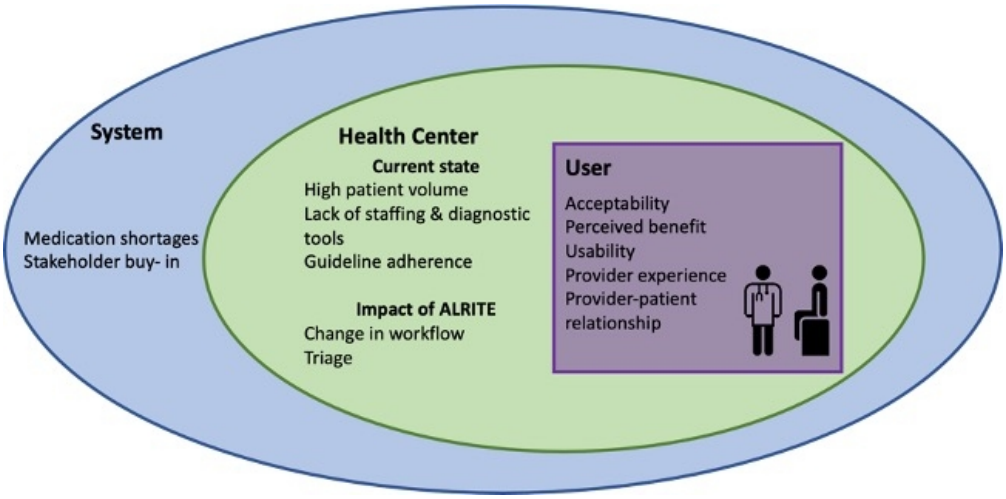

Figure 2. Frontline health workers' perspectives of determinants of ALRITE implementation.

228x112mm (72 x 72 DPI)

In-depth Interviews: Facilitator's Guide

I. Basic information

Tell me about your health center:

- how busy
- proportion of children you see vs adults
- common problems that children come with
- use of WHO IMCI routinely
- when thinking specifically about respiratory disease in children,
  - what is the range of severity?
  - Diagnostic tools available?
  - Treatment?
  - Diagnoses?
  - Referral to hospital? Referrals to specialty care?
  - How comfortable are providers in assessing and treating children?
  - What kind of training do they receive? Is there any refresher training or CME?
  - What are the biggest challenges at your health center in diagnosing and treating children with respiratory illness?
  - how common do you think asthma/recurrent wheezing is in the young children that you see?
  - Which asthma medicines do you commonly use in this health facility? Availability of asthma medications both in the clinic and to take home?

II. Brief demonstration of ALRITE

This app is 27 Mb. Do you think providers would be willing/interested in downloading to their personal device?

Start with brief demonstration, then give time to use the app.

III. General comments – ALRITE tool as mobile app (spend less time here)

- What did you like about the app?
- What did you think could be improved?
- How could this app help fill a need in your health center? What parts of the app could be the most helpful?
- Where do you see challenges with using the app?

IV. Feasibility of ALRITE tool

1) Bronchodilator timing and reevaluation.

- Tell me about use of bronchodilators in this clinic. Are they often prescribed? How are they given (oral/inhaler/nebulizer)? How are they supplied to the clinic? How are they supplied to the patient?
- This tool requires reassessment if a bronchodilator is given to evaluate whether it was helpful or not. How is that different from current practice? Is reassessment usually done?
  - What are barriers not to reassess?

2) Integration into clinical practice

- How can we avoid extra work that may be caused by using the app?

- Biggest challenges/barriers to use?
- What kind of training is required to use the app successfully?
- Interest in using stored information in the app as a form of electronic medical record?

If there's time (and hasn't been addressed during the interview)…

What is the supply chain like for bronchodilators and other medications? Are there some that are always reliably available vs others?

Limitations/challenges that you see regarding resource availability? If so, what specifically?

Challenges with diagnosis of asthma

- can patients access inhaled bronchodilator, spacers if they were helpful
- how often do you refer for specialty care; for what indications; level of respiratory support
- how common do you think asthma/recurrent wheezing is in the young children that you see
- Is there a stigma associated around the diagnosis of asthma?
- Availability of asthma medications both in the clinic and outpatient. Pharmacy – how often dispensed.

What supply is like in pharmacy. How often prescribed by clinicians?

- workflow of a patient from start to finish
- Limitations/challenges that you see regarding resource availability? If so, what specifically?

Focus Group: Facilitator's Guide

I. Brief demonstration of ALRITE (5 min)

This app is 27 Mb. Would you be willing/interested in downloading?

Outline for focus group

1. Information about your health center
2. Feedback on ALRITE app
3. Feasibility of using app within health setting

II. Basic information

Please raise hand if:

a. you own a mobile phone
b. that mobile phone is a smart phone
c. you regularly use applications on your phone (ex: Facebook, Whatsapp, games…)
d. you have used a mobile health application
e. you have completed the WHO IMCI training

(count and record for each)

Ice breaking questions (choose 1 or 2)

- how often do you see kids compared to adults in your setting?
- What is the typical workflow of children coming into clinic with respiratory complaints? *(how patients move from arrival to discharge and treatment)*
- What are the most common diagnoses that you give to children who come to clinic with respiratory symptoms?
- what kind of equipment and treatments do you have to take care of children with respiratory disease?

III. General comments – ALRITE tool as mobile app (25 min)

- What are your general thoughts about the app?
- What did you think could be improved?
- Is there anything that you would remove from the app? Or add?
- Would this be something you would prefer to have on your personal phone or keep on a hospital phone/tablet?
- How could this app help fill a need in your clinical setting?
- Where do you see challenges with using the app?

IV. Feasibility of ALRITE tool (20 min)

3) Bronchodilator timing and reevaluation.

- Tell us about your experience treating children with inhaled bronchodilators.
- The ALRITE app asks to reassess children after receiving a bronchodilator after 10 minutes. If you give bronchodilators to children, do you typically reassess them afterwards? Tell more about it. What are the challenges to perform a reassessment?

4) Integration into clinical practice

- How do you think using this app would change your workload?

- Do you think this app will change the flow of patients that you described earlier? Please elaborate.
- Biggest challenges/barriers to use?

V. IMCI decision tree & Respiratory assessment (if there is time)

- How does this protocol/decision tree follow how you currently assess patients in your clinic?
- Do you think the application impacts your ability to perform respiratory assessment? If so, how? If not, what would make it more useful?

Closing comments

Introduction to ALRITE & Usability test

Description of ALRITE

ALRITE is a mobile health application that was created to help diagnose and manage acute respiratory illnesses in young children. The goal of the app is to provide decision support to healthcare providers for children with acute respiratory complaints. The app contains a decision tree based on the World Health Organization's (WHO) Integrated Management of Childhood Illness (IMCI) case management guidelines.

One unique addition is that ALRITE will guide you through a respiratory assessment to help decide on whether a bronchodilator trial may be beneficial. Globally, wheezing illnesses are under-recognized and could contribute to severe respiratory illness in young children.

After the assessment, ALRITE will provide most likely diagnoses and treatment recommendations based on the information provided: 1) pneumonia, 2) pneumonia + wheezing illness, 3) severe disease requiring urgent referral/intervention, or 4) upper respiratory infection (supportive care only).

Instructions to participant:

We will ask you to complete a series of tasks using simulated clinical scenarios. There is no time limit or one single solution to completing each task. The study is designed to test the app and not you. You are welcome to ask me any questions that you have while completing the task. There may be times in the study where I do not answer your question because we are interested in seeing how you solve the problem. I will let you know when I cannot answer your question.

As you complete these tasks, we are going to ask you to think aloud as you work. Thinking aloud will help provide us an idea of what you are thinking as you are completing the task. We understand that you may forget to think aloud. If this happens, we ask you to tell us what you are thinking about. After each task is completed, I will ask you a few questions about the task. After all tasks have been completed, I will ask you a few questions about your overall experience of the ALRITE mobile application. If any of the questions are unclear, please ask for clarification.

We ask that during the scenarios, you imagine that you are using the app in the middle of a busy clinical shift and answer the questions as such.

Participant Comments & Feedback

Participant comments are verbal cues that indicate successes and failures in the app. We will record these comments digitally for later review as well as notetaking during the interview. Participants will be asked to answer a brief survey after completing the interview.

Errors

Errors are mistakes that the participants make while using the app that slows or stops the participant from completing each task. This data is critical for fixing errors and increasing efficiency in the app. These errors will be documented by the notetaker.

Scenario 1:

Task 1: Input information provided into the app to determine whether a bronchodilator trial is recommended.

A new patient enters your clinic with the following circumstances:

- *Name: (choose your name)*
- *Female*
- *Birthdate (choose a date where the child is between 4-6 months old)*
- *Alert and playful*
- *Not Vomiting or convulsing*
- *No difficulty eating or drinking*
- *Coughing for 10 days*
- *No HIV exposure risk*
- *This is her third episode of coughing/difficulty breathing episode since birth.*
- *On exam, her temperature is 37.3C. Oxygen saturation 94%. Respiratory rate 64. She has moderate chest indrawing. No Stridor. When you listen with a stethoscope, you hear wheezing when she inhales and exhales.*

Task 2: Read aloud whether a bronchodilator trial is recommended. If recommended, please find the tutorial on how to administer the bronchodilator and talk through how to administer to your patient. Input that you have administered the bronchodilator in the app.

Scenario 2:

Task 3: Input information for the respiratory assessment using the video of a child provided.

A new patient enters your clinic with the following circumstances:

- *Name: (choose a friend's name)*
- *Male*
- *Birthdate (choose a date where the child is 3 years old)*
- *Alert and playful*
- *Not Vomiting or convulsing*
- *No difficulty eating or drinking*
- *Coughing for 7 days*
- *No HIV exposure risk*
- *This is his second episode of coughing/difficulty breathing episode since birth*

Watch video and record respiratory assessment

Task 4: Read aloud whether a bronchodilator trial is recommended. Then close the encounter and return to the home screen.

Scenario 3:

Task 5: Return to your first patient's encounter (Scenario 1). Is she ready for re-assessment? How do you know?

If ready, please input her follow up examination outlined below.

- *Name: (your name)*
- *After the bronchodilator, she seems to be breathing a little easier than before the trial. On exam, her oxygen saturation 95%. Respiratory rate 54. She has mild chest indrawing. She still has wheezing but only when she exhales.*

Task 6: Talk through the diagnosis and treatment recommendations provided by the app.

Reporting checklist for qualitative study.

Based on the SRQR guidelines.

		Reporting Item	Page Number
Title			
	#1	Concise description of the nature and topic of the study identifying the study as qualitative or indicating the approach (e.g. ethnography, grounded theory) or data collection methods (e.g. interview, focus group) is recommended	1
Abstract			
	#2	Summary of the key elements of the study using the abstract format of the intended publication; typically includes background, purpose, methods, results and conclusions	2
Introduction			
Problem formulation	#3	Description and signifcance of the problem / phenomenon studied: review of relevant theory and empirical work; problem statement	4-5
Purpose or research question	#4	Purpose of the study and specific objectives or questions	5
Methods			
Qualitative approach and research paradigm	#5	Qualitative approach (e.g. ethnography, grounded theory, case study, phenomenolgy, narrative research) and guiding theory if appropriate; identifying the research paradigm (e.g. postpositivist, constructivist / interpretivist) is also recommended; rationale. The rationale should briefly discuss the justification for choosing that theory, approach, method or technique rather than other options available; the assumptions and limitations implicit in those choices and how those choices influence study conclusions and	8

		transferability. As appropriate the rationale for several items might be discussed together.	
Researcher characteristics and reflexivity	#6	Researchers' characteristics that may influence the research, including personal attributes, qualifications / experience, relationship with participants, assumptions and / or presuppositions; potential or actual interaction between researchers' characteristics and the research questions, approach, methods, results and / or transferability	7-8
Context	#7	Setting / site and salient contextual factors; rationale	5-6
Sampling strategy	#8	How and why research participants, documents, or events were selected; criteria for deciding when no further sampling was necessary (e.g. sampling saturation); rationale	6,8
Ethical issues pertaining to human subjects	#9	Documentation of approval by an appropriate ethics review board and participant consent, or explanation for lack thereof; other confidentiality and data security issues	9
Data collection methods	#10	Types of data collected; details of data collection procedures including (as appropriate) start and stop dates of data collection and analysis, iterative process, triangulation of sources / methods, and modification of procedures in response to evolving study findings; rationale	7-9
Data collection instruments and technologies	#11	Description of instruments (e.g. interview guides, questionnaires) and devices (e.g. audio recorders) used for data collection; if / how the instruments(s) changed over the course of the study	7, supplement
Units of study	#12	Number and relevant characteristics of participants, documents, or events included in the study; level of participation (could be reported in results)	9
Data processing	#13	Methods for processing data prior to and during analysis, including transcription, data entry, data management and security, verification of data integrity, data coding, and anonymisation / deidentification of excerpts	7
Data analysis	#14	Process by which inferences, themes, etc. were identified and developed, including the researchers involved in data analysis; usually references a specific paradigm or approach; rationale	8

Techniques to enhance trustworthiness	#15	Techniques to enhance trustworthiness and credibility of data analysis (e.g. member checking, audit trail, triangulation); rationale	8
Results/findings			
Syntheses and interpretation	#16	Main findings (e.g. interpretations, inferences, and themes); might include development of a theory or model, or integration with prior research or theory	9-19
Links to empirical data	#17	Evidence (e.g. quotes, field notes, text excerpts, photographs) to substantiate analytic findings	10-19
Discussion			
Intergration with prior work, implications, transferability and contribution(s) to the field	#18	Short summary of main findings; explanation of how findings and conclusions connect to, support, elaborate on, or challenge conclusions of earlier scholarship; discussion of scope of application / generalizability; identification of unique contributions(s) to scholarship in a discipline or field	20-22
Limitations	#19	Trustworthiness and limitations of findings	22
Other			
Conflicts of interest	#20	Potential sources of influence of perceived influence on study conduct and conclusions; how these were managed	24
Funding	#21	Sources of funding and other support; role of funders in data collection, interpretation and reporting	24