End-user acceptability of a prototype digital stethoscope to diagnose childhood pneumonia

Citation for published version:
Joarder, T, Tune, SNBK, Islam, ASMDA, Islam, A, Roy, AD, D.McCollum, E, Nair, H, Cunningham, S, McLane, IM, Shahidullah, M, H.Baqui, A & Ahmed, S 2023, 'End-user acceptability of a prototype digital stethoscope to diagnose childhood pneumonia: A qualitative exploration from Sylhet, Bangladesh', *BMC Digital Health*, vol. 1, 26. https://doi.org/10.1186/s44247-023-00027

Digital Object Identifier (DOI):
10.1186/s44247-023-00027

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published In:
BMC Digital Health

https://doi.org/10.1186/s44247-023-00027-y

BMC Digital Health

RESEARCH

Open Access

End-user acceptability of a prototype digital stethoscope to diagnose childhood pneumonia- a qualitative exploration from Sylhet, Bangladesh

Taufique Joarder[1], Samiun Nazrin Bente Kamal Tune[2], ASMD Ashraful Islam[3], Arifa Islam[3], Arunangshu Dutta Roy[3], Eric D. McCollum[4,5], Harish Nair[6,7], Steven Cunningham[8], Ian Mitra McLane[9], Mohammod Shahidullah[10], Abdullah H. Baqui[4] and Salahuddin Ahmed[3,6,11*]

Abstract

Background Considering the high frequency of respiratory infections among children in low- and middle-income countries (LMICs), the World Health Organization (WHO) developed a pragmatic guideline for managing pneumonia in low-resource settings. The guideline's low specificity leads to many false-positive pneumonia cases receiving antibiotic treatment. Integrating diagnostic technology to incorporate lung sounds into WHO guidelines could improve childhood pneumonia diagnosis and management. This qualitative study aimed to explore the acceptability of a prototype digital stethoscope device among potential end-users in Bangladesh.

Methods We conducted four focus group discussions (FGDs) with beneficiaries and service providers who used a 2018 digital stethoscope prototype. The data collection was conducted in November 2020. The study was carried out at Zakiganj Upazila (sub-district) of Sylhet district of Bangladesh. A total of 34 respondents, including parents of under-5 children, Community Health Care Providers (CHCPs), and community leaders were enrolled. Two researchers (TJ and a research assistant (not a co-author of this manuscript) conducted the FGDs. Verbatim transcripts were prepared, and translations were completed. Coding was executed in Microsoft Excel, and relevant quotes were extracted to ascertain the emerging themes. To ensure validity, two researchers coded the dataset independently and inconsistencies were resolved through discussion.

Findings Mothers were more aware of the digital stethoscope than fathers. Except for the female community leaders, male leaders were unaware of the stethoscopes. Most CHCPs had positive perceptions of the digital stethoscope. They appreciated stethoscope training as they learned about new technology and diagnostic approaches. The users mentioned several technical shortcomings of the prototype device. A few stakeholders expressed dissatisfaction with the level of community involvement and information sharing from the study. The use of the device plummeted

*Correspondence:
Salahuddin Ahmed
sahmed773@yahoo.com
Full list of author information is available at the end of the article

during the COVID-19 pandemic for fear of infection, to counteract which the CHCPs cleaned the device with chlorhexidine after every application as a precaution.

Conclusion Overall, device use was supported by stakeholders despite perceptions that the prototype had some technological limitations, community engagement was suboptimal, and the COVID-19 pandemic caused disruptions. Stronger community engagement, addressing technological issues, and further research on its health systems application would improve the acceptability and effective use of the digital stethoscope.

Keywords Digital stethoscope, Childhood Pneumonia, Bangladesh

Background

Respiratory tract infections, including pneumonia, are a major killer of children worldwide. Pneumonia is one of the leading causes of mortality in children aged below five years worldwide [1]. While radiologic imaging is commonly used to diagnose pneumonia [2], it is estimated that approximately half of the world's population does not have access to imaging facilities [3]. Availability, accessibility, and quality of care are important factors hindering care-seeking. More than 75% pneumonia deaths occur in sub-Saharan Africa and South-East Asia [4]. Care-seeking for children with acute respiratory infections (ARI) is one of the sustainable development goals (SDG) indicators (indicator 3.8.1) [5]. This indicator has improved in Bangladesh over the last few years, but the rate is still low at 46.4% [6].

Given the high burden of respiratory infections among children in low- and middle-income countries (LMICs), the World Health Organization (WHO) developed a separate guideline for managing pneumonia in resource-limited settings. In these settings, the WHO guideline promotes antibiotic use for all children with cough and/or difficulty breathing, and with rapid breathing and/or lower chest wall indrawing [7]. Due to a lack of diagnostic specificity of the guidelines, more than half of children incorrectly receive antibiotic treatment, which increases treatment costs, health system pressure, and also antimicrobial resistance.

The use of novel diagnostic technology, applicable in low-income settings, may be a solution to these challenges [8]. A stethoscope for auscultating lung sounds could improve diagnosis, but this device has some limitations in low-resources settings like Bangladesh. First, using a conventional stethoscope requires advanced clinical skills, which is difficult to ensure in rural areas with few physicians. Second, its application demands a quiet environment, which may be difficult to find in crowded rural health centers such as Community Clinics (CCs) in Bangladesh. A technology that overcomes the limitations of standard conventional stethoscopes and, at the same time, is inexpensive and acceptable to end-users could be a transformative solution [9].

We conducted a qualitative study in Bangladesh to explore the acceptance of a prototype digital stethoscope for children among potential end-users.

Description of prototype digital stethoscope

Engineers, physicians, and public health experts at Johns Hopkins University, Baltimore, USA collaborated to develop a prototype device that uses digital sensing technology for sound capture, active acoustics for noise cancellation, and artificial intelligence (AI) to assist health workers in diagnosing pneumonia [10]. A detailed description of the device is available in Supplementary file 1.

The prototype digital stethoscope was designed for non-traditional clinical settings, such as rural or walk-in clinics, homes, or low-resource areas, to be used by both trained and untrained personnel. It is equipped with advanced onboard and real-time algorithms that can detect adventitial lung sounds in recordings and improve the quality of the body sounds detected by the device through adaptive noise cancellation and the use of an externally facing microphone, mitigating any ambient noise typically present in non-traditional settings [9].

The device features multiple microphones and proprietary active noise suppression. One of the key advantages of the multiple microphone sensing array design is that the digital stethoscope does not require precise placement on the body, potentially permitting healthcare workers or carers with minimal training to also use the device. The adaptive noise suppression algorithm relies on comparing the signal from the sensor head to that obtained from an externally facing microphone. The algorithm operates through multiband spectral subtraction based on a classic, active signal denoising approach. As opposed to passive approaches such as low pass and high pass filtering found in current commercial products, this technique offers a real-time adaptation of the algorithm given the ambient environment. A classic spectral subtraction scheme has been extended into multiple frequency bands with weighted subtractions of each band that consider the signal-to-noise ratio of both the current frame and frequency component, which allows for more accurate adaptation to unseen environments and sounds.

An associated prototype mobile application has been designed, and this application takes recordings from the device via Bluetooth and associates the recording with a specific location and a nonidentifiable patient ID before transmitting it to a secure cloud database. This application can be applied to support clinical care and research projects involving the stethoscope. The application guides participants through the data collection process at four preset locations on the body -two from back and two from front chest [9] and subsequently asks participants questions regarding symptoms at the time of recording. The application can also push notifications and reminders daily to ensure that recordings are conducted. This application standardizes the study procedure across all the study participants when conducting studies at multiple sites.

Study objective

This is a qualitative study to explore the acceptability of the 2018 prototype digital stethoscope system among potential end-users. This study is a part of a larger study [9] aiming to compare automated lung sound classifications by digital auscultation based on trained pediatricians' reading, as part of a broader effort to improve the accuracy of childhood pneumonia diagnosis.

Methods

Study design, duration, and site

This qualitative study used a narrative research approach [11] and involved focus group discussions (FGDs) with beneficiaries and service providers using the 2018 digital stethoscope prototype. This study was conducted from a constructionism [12] point of view as it is primarily concerned with the individual's active role in constructing knowledge through their interactions with the environment, in our case, the application of the digital stethoscope in Zakiganj upazila (sub-district) of Sylhet district of Bangladesh in November 2020. The field data collection was carried out between 28 and 29 November 2020. The district map of the study site is shown in Fig. 1.

Study population

A total of 34 different respondents participated in four FGDs. Seventeen carers (Mothers, $n=10$; Fathers, $n=7$), eight Community Health Care Providers (CHCPs), and nine community leaders were included as FGD participants. The details of the methods followed are mentioned in Table 1.

Data collection and tool development

The first author (TJ) and a research assistant (not a co-author of this manuscript) conducted the FGDs. The selection of participants was done purposively. For carers, we generated a list (from the database) of enrolled children from which male and female carers were independently approached and were invited to participate in the discussion. Those who were interested in participating were selected and called for the FGD. Community leaders who were members of the CC support groups were approached and invited to participate in the discussion. Those who agreed were selected. All CHCPs who took part in the study activities at their CC were invited to participate in the discussion. The FGDs were held at the study office in Zakiganj, where the main trial on the effectiveness of the digital stethoscope is coordinated. Considering the COVID-19 situation, we placed each participant in alternate chairs around a large conference table, maintaining at least a 1-m distance. We also provided face masks during the FGD and kept the windows open to promote adequate ventilation. FGDs were conducted at the Projahnmo Research Foundation (PRF) Zakiganj office, but were held in a private room to ensure confidentiality and reduce social desirability bias [13]. The data collectors identified themselves as external consultants with no affiliation to the project implementers.

Each of the four FGDs consisted of 7–10 participants, selected through a purposive sampling method. The FGDs had the following types of participants:

FGD 1: Mothers of the beneficiary children
FGD 2: Fathers of the beneficiary children
FGD 3: CHCPs who used the digital stethoscope prototype
FGD 4: Community leaders from the intervention area

The first author (TJ) of this paper facilitated the sessions while a Research Associate (RA) obtained written informed consent, which included permission for the audio recording of the FGD, and took written notes. Each FGD, lasting from 60 to 105 min, was conducted in Bengali, the native language of the respondents and the researchers. All participants received lunch (arranged at the PRF Zakiganj office) and transportation cost reimbursement. The summary of the open-ended questions in the FGD topic guides is given below:

1) Initial or ice-breaking questions, whether the participants were informed of the use of the digital stethoscope in the area.
2) General perception regarding the digital stethoscope, whether it is a good or a bad innovation.
3) Training on the use of the digital stethoscope (question for health workers and community leaders only)

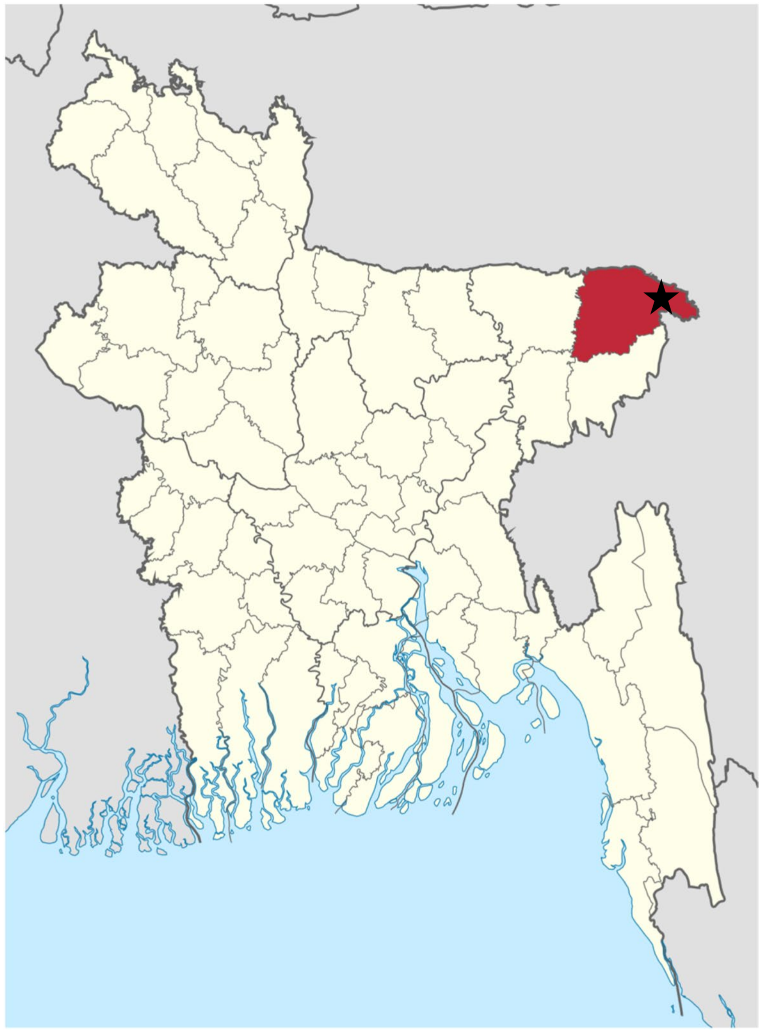

Fig. 1 Study site in Zakiganj Upazila, Sylhet District, Bangladesh. Source: The map image is freely available for use from https://commons.wikimedia.org/wiki/File:BD_Sylhet_District_locator_map.svg

Table 1 Total number of participants included in the FGDs

Method	Tool	Participants	Number
FGD	Topic guide for carers (Mothers and Fathers)	Mothers	10
		Fathers	7
	Topic guide for Community Health Care Providers (CHCPs)	CHCPs	8
	Topic guide for community leaders	Community leaders	9
Total number of respondents in 4 FGDs			34

The purpose of using different topic guides for different types of respondents in FGDs was to explore varied perspectives on the acceptability of the prototype digital stethoscope used for the study among stakeholders

4) Cooperation of beneficiaries with health workers to use the digital stethoscope (question for beneficiaries only)
5) Positive experiences using the digital stethoscope
6) Negative experiences using the digital stethoscope
7) Experience regarding troubleshooting support
8) Supervision of the digital stethoscope use (question for health workers and community leaders only)
9) Adaptation in work or the health center for using the digital stethoscope (question for health workers only)

10) Improvement potential
11) Scaleup potential (question for health workers and community leaders only)
12) Comparison with the conventional acoustic stethoscope
13) Summary and recommendations

The tools are available in the Supplementary file 2.

Data analysis

The FGDs were immediately transcribed and translated by the RA. For analysis, we adopted the conventional content analysis method [14], which is appropriate in the scarcity of existing literature on a topic, as this method avoids using preconceived themes. We immersed ourselves in the data to allow new insights to emerge, then developed the inductive categories through the following steps: familiarizing ourselves with the data by listening to the records and reading the transcript, developing coding schema in Microsoft Excel based on the questions mentioned above, noting the first impressions followed by labeling the text segments by newly emerging codes, merging the similar-meaning codes, then sorting the codes into larger categories based on how different codes are related or linked. Appropriate quotations were extracted to substantiate the emerging themes. In order to increase validity, TJ and another qualitative researcher independently coded the dataset. We discussed and reached an agreement regarding the coding if any discrepancy was found. To increase the trustworthiness and credibility of the data, we used source triangulation [15] by conducting FGDs with various stakeholders, including mothers, fathers, CHCPs, and community leaders. This approach allowed us to compare and validate different perspectives on the prototype digital stethoscope.

Results

Background characteristics of the participants

A total of 34 respondents participated in four FGDs (Table 2). The respondents' age ranged from 21 to 63 years; 16 were males, and 18 were females. Apart from the CHCPs, the other three groups of participants were heterogeneous in education and occupation. Female respondents other than the CHCPs were primarily housewives.

General perception regarding the digital stethoscope prototype

All the mothers knew about the digital stethoscope, but the fathers did not. Community leaders did not know much about the digital stethoscope, except for the female leaders, who learned about it from beneficiary mothers in their families. Mothers reported being slightly nervous initially, but they became familiar in subsequent uses, and the baby was calmer than the previous encounter. Expressing approval for the digital stethoscope, a mother said,

> *"Baby always moves a lot. It is normal. As a mother, I knew the digital stethoscope is good for my baby. It helps him get cured of pneumonia. So, I cooperated with the health worker so that she could use the device well." [Mother, FGD 1]*

Health workers knew how to select the beneficiaries and apply the digital stethoscope. They have been using it for the last one and a half years, and they apply it daily to two to three children on average. Most of them had a positive perception regarding the digital stethoscope. The reasons they cited were: first, digital equipment is generally good as they give more accurate results than non-digital ones, and second, it is a new technology, and anything new is usually better than the old.

Table 2 Characteristics of the FGD participants

FGD	Age Range (Years)	Male/ Female	Education	Occupation
Mothers	21–40	0/10	Most completed 8th class or secondary school certificate ($n=8$), one completed 5th class, and one could only sign	Most were housewives ($n=9$), and one tailor
Fathers	29–52	7/0	Most completed 9th class or secondary school certificate ($n=4$), two could only sign, and one had a master's degree	Farmer ($n=2$), day laborer ($n=2$), one poultry farmer, one teacher, and one businessman
CHCPs	29–36	3/5	Most held a bachelor's degree ($n=4$), a master's degree ($n=3$), and one had a higher-secondary school certificate	All were full-time health workers
Community leaders	38–63	6/3	Most completed 10th class or higher-secondary school certificate ($n=5$), three completed between the 3rd and 5th class, and one completed bachelor's degree	Most were businessmen ($n=4$), two farmers, two homemakers, and one day laborer

Training

All participating CHCPs received a three-day training at the Zakiganj Upazila Health Complex (UHC) in April 2019. The local PRF staff and an overseas doctor provided the training. The training included using a pulse oximeter, detecting shortness of breath, measuring mid-upper arm circumference (MUAC), and use of the digital stethoscope on infants and children. They received two refresher trainings in July 2019 and January 2020.

The participants appreciated the training as they could learn about new technology and diagnostic approaches. The training was interactive (they could give feedback), detailed, and included practical demonstrations. They liked the training venue as it was a new place outside their workplace, getting to know new colleagues working in different CCs, good food, the presence of a 'foreign' trainer, and the amount of remuneration. They felt that another refresher training would be useful. The only negative aspect of the training was that there was not sufficient water at the training venue, and they wished the refresher training had been longer,

> *"Practical demonstration was good, training was good, but I wish we received refresher training for two days instead of one." [Male CHCP, FGD 3]*

Community leaders needed to be sufficiently engaged in the training, and only one out of the nine participants knew about the training. However, they did not hear any complaints regarding the training, in general.

Support and supervision

The 14 CHCPs (later reduced to nine) received support from two Field Research Assistants (FRAs) and two physician supervisors. The FRAs provided technical assistance as requested by the CHCPs and replaced malfunctioning digital stethoscope prototypes when necessary. The two physician supervisors regularly visited the CHCPs to supervise patient enrollment and record-keeping; and conducted quality control activities. Apart from the formal training at the Upazila Health Complex (UHC), the CHCPs received regular onsite training on-demand by the PRF staff. CHCPs said that the PRF staff tried to solve the problem immediately whenever they faced any technical glitches. However, sometimes it took a long time, and the mothers had to wait for two to three hours. A mother said,

> *"There was no charge in the device. When the health worker called, another health worker [actually an FRA] came. It took around two to two and a half hours to solve the problem. Eventually, the new health worker [FRA] brought another device and conducted my baby's chest examination." [Mother, FGD 1]*

The CHCPs were satisfied with the quality control activities and the supervisory support they received. According to the CHCPs, the actions of the PRF staff included: using standard devices to check if the measurements done by the CHCPs were correct, shadowing their activities to assess if there were problems in following the instructions provided by the project, waiting in the CCs for the whole day if there was a long gap in patient enrolment. CHCPs appreciated the friendly behavior of the PRF supervisors,

> *"This is good that we never felt they [PRF staff] are checking on us. We feel good when they come to our CC. We get whatever we request them." [Female CHCP, FGD 3]*

Positive experiences

According to mothers, health workers looked confident with the digital stethoscopes, and the babies were not afraid. They also felt that a digital instrument must be more accurate. A father said,

> *"This is the digital era. Everything digital is good. It [the digital stethoscope] should be good too as scientists have put their brain into it." [Father, FGD 2]*

Some health workers used a regular conventional stethoscope before but preferred the digital stethoscope prototype as they did not have to interpret the sounds. According to them, beneficiaries were happy too, so much so that some non-beneficiary mothers complained about why their baby was not examined by the digital stethoscope. Reflecting on its acceptability among the mothers, a CHCP said,

> *"Usually, the extreme-poor mothers visit the Community Clinic. They become happy that they are getting something [examined by the digital stethoscope] that even the big hospitals cannot offer." [Male CHCP, FGD 3]*

Some other benefits of using the digital stethoscope, as reported by the participants, are: easy to put the chest piece on the baby's chest (reported by eight mothers and three CHCPs), takes a short time to record the lung sound (reported by three mothers and three CHCPs, while several others complained of taking too long), does not require time or technical skills to clean it, and storage is easy and does not require much space.

Negative experiences

Some beneficiaries were unsure how the health worker would listen to the lung sound in the digital stethoscope, while the patients could clearly understand the mechanism in a regular stethoscope. They doubted the health workers' ability to correctly record and interpret the sound. Most mothers complained about the long time required to get enrolled and examined, especially on the first day. A mother expressed,

> *"Examination took a long time initially, around 20 minutes, but later the time came down." [Mother, FGD 1]*

Health workers also accepted the complaints of taking a long time to enrolment. Other demand-side problems, as reported by the CHCPs, include: digital stethoscope patients' crowded out other patients coming to the CC, patients become restless when the enrolment takes a long time and some suspect that the device might harm their child. A CHCP shared his experience,

> *"When the red light of the pulse oximeter is lit, they thought we were sucking out blood from the baby. Since we check oxygen saturation, some patients became suspicious of the digital stethoscope too." [Female CHCP, FGD 3]*

CHCPs reported some logistic or work-related challenges too. Reportedly, due to the additional time spent on digital stethoscope-related activities, some of their work, such as record keeping and reporting, were hampered. Other challenges include lack of electricity to charge the device, not getting troubleshooting support in time, concern about privacy as CHCP may initiate the digital stethoscope recording accidentally at times, anxiety about their children getting electrified while charging the digital stethoscope at home, and difficulty in carrying the extra load of the device regularly. A participant said,

> *"Carrying these instruments is difficult as I travel by motorcycle. [Other CHCPs added] Previously, we kept our bag in the health center; now we have to carry the extra load as we cannot leave such an expensive instrument there." [Male CHCP, supplemented by other participants, FGD 3]*

CHCPs reported some technical problems with the digital stethoscope too. For example, the users need to record lung sounds from four locations, but the device sometimes stopped after recording the first sound. Sometimes the recording continues until someone from the PRF office provides technical support to stop it or change the device altogether. They also complained about the prototype's durability as the rubbers around the chest piece and other parts of the device eroded since the device was a 3-D printed prototype. Without a visual cue on the prototype device, users were often confused about whether the recording was done correctly. Sometimes the devices froze (becomes unresponsive), started auto-recording, drained their charge quickly, and did not record. A CHCP said,

> *"In front of my Community Clinic, there is a garage. Passengers talk. Then their talking is recorded more than the lung sound." [Female CHCP, FGD 3]*

Improvement potentials

The participants proposed several recommendations related to the technical aspects of the device itself, its functionality within the larger health system, or some demand-side requests for better application. The technical recommendations include solving the problem of the device freezing or becoming unresponsive, adding a display to show the reading, adding a holder to hold it easily in hand or hang it on the wall, increasing the battery life, using more durable, non 3-D printed materials for the chest piece and the surrounding rubber, adding indicator lights (green, yellow and red) to indicate the lung sound findings, and decreasing the number of chest positions for recording (currently there are four positions). A participant said,

> *"Sometimes the baby starts crying after recording from three positions. Then we cannot complete the recording. So, it would be good to record from fewer positions." [Male CHCP, FGD 3]*

In order to improve the functionality of the device within the health system, the participants recommended providing health workers with a back-up device so that they can replace it without having to keep the patients waiting, giving a good quality power bank to all health workers (currently, it is provided only in the CCs without electricity) so that they do not worry about the device turning off of the low battery, exempting health workers from any additional reporting related to the device use (since the prototype is currently being used as part of a study, currently, they have to take consent and fill out a register book). Community leaders emphasized informing the community people of the device for better acceptability,

> *"Even being a community leader, I don't know this [the digital stethoscope] is available in my area. Now suddenly, you have come asking about this. This should not have happened. We must be informed first." [Male community leader, FGD 4]*

Beneficiaries demanded that the digital stethoscope should be made available in local private pharmacies as these serve as their first point of care,

> *"Community Clinics are open only two or three days a week and only for a limited time. But the pharmacy is available even at 3 AM in the morning. If I walk just five minutes, I come across at least three or four pharmacies. So, it [the digital stethoscope] would be more useful in pharmacies. It would be more useful in the hand of informal providers." [Father, FGD 2]*

They also said that using the digital stethoscope should not be limited to pneumonia only; a device like this should be upgraded to detect other diseases, such as heart disease, tuberculosis, or even COVID-19. A participant mentioned,

> *"If this device could detect more diseases, I would purchase one for myself to keep in my home. Just like we keep a thermometer in our home." [Father, FGD 2]*

Albeit having shared their concerns and recommendations, the participants gave overall positive feedback regarding the digital stethoscope and emphasized its usefulness in the rural Bangladeshi context. They expressed their commitment to continue using the digital stethoscope should the device be made available and scaled up. A health worker expressed,

> *"We commonly observe breathing difficulties, coughing, and pneumonia-related problems in children. If this [the digital stethoscope] remains available, then the people of the area will be benefited, plus the other people will also be benefited if the device is scaled up to other areas." [Male CHCP, FGD 3]*

Impact of COVID-19

Concerns regarding COVID-19 were expressed in all FGDs. The fathers and the community leaders wished the digital stethoscope could detect COVID-19, as going to the district town to get tested for the disease was difficult for them. Mothers were afraid to go to the CCs for fear of contracting COVID-19. The CHCPs also supported the beneficiaries' remarks and confirmed that the use of the digital stethoscope was decreased due to the COVID-19 situation,

> *"Previously, more children came on whom we used the digital stethoscope. During the COVID-19 lockdown, Community Clinics were closed. Now that we have restarted, fewer children are coming." [Female CHCP, FGD 3]*

In order to address the concerns, CHCPs proactively took some cautionary measures. They said they cleaned the device with cotton before and after applying it to every child. They explained how they use the readily available chlorhexidine solution to wipe the device after each use,

> *"I clean it [the digital stethoscope] with hexisol [chlorhexidine]. I mix a little bit of water with the hexisol and clean the digital stethoscope, weight scale, pulse oximeter, and all the instruments that touch the baby. After completing one child's work, and before doing it for another child, we clean it with hexisol." [Male CHCP, FGD 3]*

Discussion

Digital health technologies hold great potential to benefit LMICs, but many innovations fail to reach full scale due to the lack of acceptability of different stakeholders. By identifying the issues discouraging them from adopting innovation, technology developers and policymakers can produce better technology that is more context appropriate and make better decisions to allow the interventions to reach scale [16]. The most important findings from this qualitative study are: i) The stakeholders, in general, approve of the digital stethoscope; ii) The users reported some technological limitations of the 2018 prototype device; iii) Some stakeholders complained about insufficient community engagement and information sharing regarding the device; iv) digital stethoscope study use during the COVID-19 pandemic faced challenges, against which health workers took proactive measures. These important points are discussed further below.

Approval of the digital stethoscope

The stakeholders we included in our study were the carers of the children who took their sick children to seek care from the CCs, the health workers who applied the digital stethoscope among the under-five children, and the community leaders residing in the catchment area of the CCs included in the study. All of them had something positive to say about the device. Carers were satisfied with modern technology that even the patients visiting large urban hospitals in Bangladesh cannot access. Providers were satisfied with PRF's training, support, and supervision activities. Community leaders did not hear complaints regarding the device from either of these two groups. To the best of our knowledge, this study was the first to evaluate how frontline workers in LMICs record the lung sounds of young children in primary-level facilities. Previously, lung auscultation with conventional stethoscopes were only available in tertiary-level healthcare facilities or by formal healthcare personnel in LMICs [8, 17].

End-user feedback on the prototype device and software application

One of the study's primary purposes was to identify users' technological, logistic, and social challenges in applying the prototype digital stethoscope in order to make iterative improvements in the technology. Our study identified some challenges with the prototype, such as difficulty in charging, needing to carry the device home daily because of security concerns with leaving the device in the clinic, and dealing with prototype software and device glitches. These include stopping of recording prematurely, not stopping the recording in due time, the durability of the 3-D printed prototype material, freezing during the application, draining the charge quickly, and picking up the ambient noise. These prototype challenges have been addressed in subsequent prototype iterations based on this end-user feedback.

Community engagement

Involving opinion leaders is crucial in diffusing innovations to the larger population [18]. Although the study conducted community sensitization activities, there was a perception among community leaders that these activities did not sufficiently inform all community leaders and members. Reviewing this study's community sensitization activities and addressing any shortcomings in future studies is likely to eliminate the likelihood of resistance and improve uptake. Our study found that the community leaders and the community's male members did not feel adequately informed of the prototype device study. It is possible that the community misunderstood that the device was a development prototype and healthcare workers were not using the device for medical decision-making.

Challenges of COVID-19

COVID-19 came as a challenge to all, as the beneficiaries were afraid to use the CCs, and the CHCPs were getting fewer patients. Consequently, we formed Patient Public Involvement Groups (PPIG) consisting of CHCPs, Community Health Workers, Health Assistants, Physicians, community leaders, religious leaders, parents of under-5 children, teachers, local journalists for their insights, approval, and support to implement the study. Despite the challenges, as per the PIGG's recommendations, the health workers carefully applied contact precautions to mitigate any disease transmission risk by an unclean digital stethoscope. They exploited an available cleansing solution (chlorhexidine, which they mixed with water) to sterilize the digital stethoscope and other instruments used. The fact that the prototype device was easy to clean facilitated its use during this time period.

Limitations of the study

The limitation of the study is that we could not achieve thematic saturation. We had to limit the number of FGDs due to time constraints and COVID-19 pandemic. Most male participants, except the CHCPs, also did not have information or familiarity regarding the digital stethoscope, which restricted their inputs.

Recommendations

Based on this qualitative study findings, we make the following three recommendations-

1. Stronger community engagement is needed:
   Stronger community engagement is necessary where the device is rolled out. Without the participation of the community and gathering their opinion regarding the device, the initiative will not be as effective. The community engagement activities for this study should be reviewed and revised to improve upon them for future studies.
2. Technological issues with the prototype device should be addressed:
   As the users mentioned, at times they faced some difficulties using the prototype device. Addressing their feedback will ensure future versions of the device are more effective and user-friendly. End-user feedback suggested to include a display showing the findings of the lung sound. A holder should be added to the device so that the recording is not turned on by inadvertent touch, and so that potentially the device could be hung on the wall. Since the prototype was 3-D printed the rubber and other materials were brittle. More durable materials should be used, especially in challenging settings like rural Bangladesh. There is a need to decrease the number of recording positions from four chest positions, as the healthcare workers indicated children had difficulty cooperating with all positions. Future research needs to address whether fewer chest positions would be adequate for diagnosis. Battery improvements can be made, as well as understanding whether the extreme environment in Bangladesh may impact battery performance. Future studies could provide users with a power bank and giving a back-up digital stethoscope could be considered if resources allow.

3. Research exploring whether the device can be effectively used by private sector healthcare workers and improvement of the community clinic's security is crucial:
   Research exploring feasibility of implementing the device with informal providers serving in the local pharmacies should be considered as this could increase access to the device. Ensuring the health facilities' security is vital so the health workers do not need to carry around the device to their homes for charging, which can be challenging in rural Bangladesh.

Conclusion

The prototype device is an early version of a digital auscultation system for diagnosing childhood pneumonia in a resource-limited setting like Bangladesh. Both the carers and the service providers seem satisfied with the prototype device. Addressing the stakeholders' recommendations would further improve the acceptability of future versions of the device and contribute to the reduction of childhood respiratory infections.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s44247-023-00027-y.

Additional file 1.

Additional file 2.

Acknowledgements

The researchers would like to express gratitude to the RESPIRE collaborators, the research team including Md. Efthakhar Mahamudul Hoque Mondol (research assistant) and all the study participants for their support throughout the data collection during the COVID-19 pandemic. The RESPIRE collaboration comprises the UK Grant holders, Partners and research teams as listed on the RESPIRE website (www.ed.ac.uk/usher/respire).

Guarantor

TJ and SA.

Authors' contributions

Conceptualization: TJ, SA. Data curation: TJ. Formal analysis: TJ, SA. Funding acquisition: AHB, SA. Methodology: TJ, ADR, SA. Supervision: SA, ASMDAI. Literature Review: TJ, SNBKT, SA. Writing original draft: TJ. Writing – review & editing: SNBKT, ASMDAI, AI, ADR, EDM, HN, SC, IMM, MS, AHB, SA. All authors read and approved the final manuscript.

Funding

This research was funded by the UK National Institute for Health Research (NIHR) (Global Health Research Unit on Respiratory Health (RESPIRE); 16/136/109) using UK aid from the UK Government to support global health research. The views expressed in this publication are those of the author(s) and not necessarily those of the NIHR or the UK Government. The funding body did not play any roles in the design of the study and collection, analysis, and interpretation of data and in writing the manuscript.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The ethical approval for the study was obtained from the National Research Ethics Committee of Bangladesh Medical Research Council, Bangladesh (Registration number: 09630012018) and Academic and Clinical Central Office for Research and Development Medical Research Ethics Committee, Edinburgh, UK (REC Reference: 18-HV-051). A Research Associate (RA) obtained written informed consent, which included permission for the audio recording of the FGD, from all the study participants. All methods were performed in accordance with the ethical principles outlined in the Belmont Report.

Consent for publication

Not applicable.

Competing interests

The authors declare the existence of a financial competing interest. IMM owns equity in the commercial entity Sonavi Labs Inc. and serves as the company's Chief Technology Officer. EDM is a paid scientific consultant to Sonavi Labs Inc. Under a license agreement between Sonavi Labs Inc. and the Johns Hopkins University, the University is entitled to royalty distributions related to technology described in the study discussed in this publication. This arrangement has been reviewed and approved by Johns Hopkins University in accordance with its conflict of interest policies. The other authors declare that they have no competing interests.

Author details

[1]SingHealth Duke-NUS Global Health Institute, Singapore, Singapore. [2]BRAC James P Grant School of Public Health, BRAC University, Dhaka, Bangladesh. [3]Projahnmo Research Foundation, Dhaka, Bangladesh. [4]Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, USA. [5]Global Program in Pediatric Respiratory Sciences, Eudowood Division of Pediatric Respiratory Sciences, Department of Pediatrics, School of Medicine, Johns Hopkins University, Baltimore, Maryland, USA. [6]Usher Institute, College of Medicine and Veterinary Medicine, University of Edinburgh, Edinburgh, UK. [7]MRC/Wits Rural Public Health and Health Transitions Research Unit (Agincourt), School of Public Health, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa. [8]Centre for Inflammation Research, University of Edinburgh, Edinburgh, UK. [9]Sonavi Labs, Baltimore, Maryland, USA. [10]Department of Neonatology, Bangabandhu Sheikh Mujib Medical University, Dhaka, Bangladesh. [11]NIHR Global Health Research Unit on Respiratory Health (RESPIRE), University of Edinburgh, Edinburgh, UK.

Received: 10 February 2023 Accepted: 22 June 2023
Published online: 13 July 2023

References

1. Liu L, Oza S, Hogan D, Chu Y, Perin J, Zhu J, et al. Global, regional, and national causes of under-5 mortality in 2000–15: an updated systematic analysis with implications for the Sustainable Development Goals. Lancet. 2016;388(10063):3027–35.
2. Mandell LA, Wunderink RG, Anzueto A, Bartlett JG, Campbell GD, Dean NC, et al. Infectious Diseases Society of America/American Thoracic Society consensus guidelines on the management of community-acquired pneumonia in adults. Clin Infect Dis. 2007;44(Supplement_2):S27-S72.
3. Fleming KA, Horton S, Wilson ML, Atun R, DeStigter K, Flanigan J, et al. The Lancet Commission on diagnostics: transforming access to diagnostics. Lancet. 2021;398(10315):1997–2050.
4. McAllister DA, Liu L, Shi T, Chu Y, Reed C, Burrows J, et al. Global, regional, and national estimates of pneumonia morbidity and mortality in children younger than 5 years between 2000 and 2015: a systematic analysis. Lancet Glob Health. 2019;7(1):e47–57.
5. SDG U. United Nations Sustainable Development Goals. New York: SDG[Google Scholar]; 2015.
6. Bangladesh Bureau of Statistics. Progotir Pathey, Bangladesh multiple indicator cluster survey 2019, key findings. Dhaka: Bangladesh Bureau of Statistics (BBS); 2019.

7. WHO/UNICEF. Joint Statement: Integrated CommunityCase Management (iCCM). Geneva: World Health Organization and United Nations Children's Fund; 2012.
8. McCollum ED, Park DE, Watson NL, Buck WC, Bunthi C, Devendra A, et al. Listening panel agreement and characteristics of lung sounds digitally recorded from children aged 1–59 months enrolled in the Pneumonia Etiology Research for Child Health (PERCH) case–control study. BMJ Open Respir Res. 2017;4(1): e000193.
9. Ahmed S, Mitra DK, Nair H, Cunningham S, Khan AM, Islam AA, et al. Digital auscultation as a novel childhood pneumonia diagnostic tool for community clinics in Sylhet, Bangladesh: protocol for a cross-sectional study. BMJ Open. 2022;12(2): e059630.
10. Elhilali M, West JE. The stethoscope gets smart: Engineers from Johns Hopkins are giving the humble stethoscope an AI upgrade. IEEE Spectr. 2019;56(2):36–41.
11. Overcash JA. Narrative research: a review of methodology and relevance to clinical practice. Crit Rev Oncol Hematol. 2003;48(2):179–84.
12. Crotty MJ. The foundations of social research: Meaning and perspective in the research process. In: The foundations of social research. 1998:1–256.
13. Smith CP. Content analysis and narrative analysis. In: Reis HT, Judd CM, editors. Handbook of research methods in social and personality psychology. Cambridge: Cambridge University Press; 2000.
14. Hsieh H-F, Shannon SE. Three approaches to qualitative content analysis. Qual Health Res. 2005;15(9):1277–88.
15. Denzin NK. The research act: A theoretical introduction to sociological methods. Piscataway, New Jersey: Transaction publishers; 2017.
16. Wallis L, Blessing P, Dalwai M, Shin SD. Integrating mHealth at point of care in low-and middle-income settings: the system perspective. Glob Health Action. 2017;10(sup3):1327686.
17. Scrafford C, Basnet S, Ansari I, Shrestha L, Shrestha S, Ghimire R, et al. Evaluation of digital auscultation to diagnose pneumonia in children 2 to 35 months of age in a clinical setting in Kathmandu, Nepal: a prospective Case-Control study. J Pediatr Infect Dis. 2016;11(02):028–36.
18. Dearing JW, Cox JG. Diffusion of innovations theory, principles, and practice. Health Aff. 2018;37(2):183–90.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.