Is a Phone-Based Language and Literacy Assessment a Reliable and Valid Measure of
Children's Reading Skills in Low-Resource Settings?

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Abstract

Purpose

Technology-based remote research methods are increasingly widespread, including learning assessments in child development and education research. However, little is known about whether technology-based remote assessments remain as valid and reliable as in-person assessments. We developed a low-cost phone-based language and literacy assessment for primary-school children in low-resource communities in rural Côte d'Ivoire using voice calls and SMS. We compared the reliability and validity of this phone-based assessment to an established in-person assessment.

Methods

685 5th grade children completed language (phonological awareness, vocabulary, language comprehension) and literacy (letter, word, pseudoword, passage reading and comprehension) tasks in-person and by phone.

Results

Reliability (internal consistency) and predictive validity was high across in-person and phone-based tasks. Children's performance across in-person and phone-based assessments were moderately to strongly correlated. Phonological awareness and vocabulary skills measured in-person and by phone significantly predicted in-person and phone-based letter, word and pseudoword reading. Oral language and decoding skills measured in-person and by phone significantly predicted in-person and phone-based passage reading and comprehension.

Conclusion

Our phone-based assessment was a reliable and valid measure of language and reading and feasible for low-resource settings. Low-cost technologies offer significant potential to

measure children's learning remotely, increasing inclusion of remote and low-resource populations in education research.

Introduction

In March 2020, the World Health Organization (WHO) declared COVID-19 (coronavirus disease 2019) a pandemic that triggered a global lockdown with consequences for nearly every sector of society, including in-person scientific research. To mitigate the public health risks of in-person research, researchers rapidly pivoted from in-person to technology-based remote data collection (Angrist et al., 2020a; Angrist et al., 2020b; Anwyl-Irvine et al., 2020; Joshi & Sudhanshu, 2021; Khurana, Kruske, et al., 2022; Khurana, Levin, et al., 2022; Koomar & Blest, 2020; Nshimbi et al., 2020). There is now an emerging area of interest in remote data collection (e.g., video calls using platforms such as Zoom or Skype). However, these pose significant challenges for child development and education research.

First, remote data collection is often inherently inequitable; virtual methods require a reliable internet connection, costly computer, smart device and/or a webcam (i.e., ‘high-tech’) to participate. Individuals and communities with little or no access to this technology are excluded from research participation. Remote data collection in child development and education research is therefore likely to exclude marginalized and vulnerable children, particularly from families who experience economic hardships, may lack sufficient language proficiency to use the technology, or have sufficient familiarity with using technology for research participation. Younger children, in particular, may be even less familiar with virtual environments, further limiting the assessment of early child development and emergent academic skills (Escudero, 2021). Such barriers exist across different communities but are significantly exacerbated in low-resource and remote communities, particularly in low- and middle-income countries (LMICs).

Second, although remote data collection in child development and education research has exploded during the COVID-19 pandemic (Farmer et al., 2020), exceedingly little research has established the reliability and validity of remote measures with children. As researchers forge forward in developing remote research methods in the ‘new normal’ COVID-19 and post-COVID-19 landscape, we must address the need for reliable and valid remote research methods inclusive of all children and communities. With these goals in mind, we developed and deployed a low-tech phone-based language and literacy assessment for primary-school children as part of an ongoing study of literacy development in a low-resource rural region of Côte d’Ivoire. We aimed to determine whether a low-cost, simple phone-based remote assessment was a reliable and valid measure of children’s language and literacy skills. We used a simple mobile phone to administer a language and literacy assessment using voice calls and SMS messaging. Simple phones are ubiquitous throughout Côte d’Ivoire, including in low-resource rural communities. Using a simple phone, rather than a smart device, obviates the need for costly internet/data access, allowing for more inclusive data collection. We compared our phone-based language and literacy assessment to established in-person language and literacy assessments administered to the same children at three different timepoints (pre-pandemic, during COVID-19 restrictions). Such insight into low-tech remote research capabilities in low-resource, rural communities can broaden the scope of data collection methods and educational research, ensuring that the evidence gathered is valid and reliable, and represents all children.

Measuring Children’s Literacy Development

Literacy Development

Reading ability comprises multiple cognitive (e.g., memory and attention) and language abilities (e.g., phonological awareness, vocabulary, language comprehension). Emergent readers

first learn to decode words by mapping sounds to letters (e.g., knowing that /m/ makes a *mmm* sound) and letter patterns (e.g., /ck/ together often make a /k/ sound). Phonological awareness (PA), the awareness of and ability to manipulate sound units, is therefore an important predictor of decoding skills (Hulme, 2002; Wagner & Torgesen, 1987). Children who perform well on tasks measuring phoneme and/or syllable awareness (e.g., phoneme identification or deletion, word segmentation, sound blending, phoneme matching) have better reading skills (Goswami & Bryant, 1990; Hulme, 2002; Jasińska et al., 2019). Similarly, word recognition also relies on children's knowledge of words; children who perform well on vocabulary tasks have better reading skills (Jasińska & Petitto, 2018; Ouellette, 2006). Children's word recognition and decoding abilities are typically measured with word and pseudoword (pronounceable, but nonexistent words; e.g., *flib*) reading tasks. As children become more skilled readers, they decode words with greater automaticity and can read and comprehend text passages. Children's reading comprehension is supported by both their decoding skills and language comprehension (the ability to make sense of what is heard and read); a theoretical model known as the Simple View of Reading (Gough & Tunmer, 1986; Hoover & Gough, 1990). A comprehensive measure of children's reading abilities, therefore, includes measures of both decoding and reading comprehension, as well as reading-related language abilities including PA, vocabulary, and language comprehension.

Technology-Based Language and Literacy Assessments

There are multiple modes of assessing children's language and literacy abilities (e.g., one-on-one assessments, group assessments [i.e., reading tests administered to a class of students], and parent or teacher reports), which can be administered in-person or remotely using technology. Researchers have increasingly incorporated digital technologies in assessments using

smartphone, tablet-based, or web-based apps. For example, Yeatman and colleagues (2021) created a web-based gamified literacy assessment that incorporated a lexical decision task (LDT) to assess word and pseudoword reading. Scores correlated with Woodcock-Johnson Letter Word Identification (Schrack et al., 2014) scores, and were a reliable and valid measure of reading skill (Yeatman et al., 2021). Other researchers have applied a hybrid approach; children complete tablet-based literacy tasks, but standardized language and reading assessments were administered in-person (O'Brien et al., 2019). Remote assessments may also be conducted using videoconferencing platforms such as Skype or Zoom. For example, Hodge and colleagues (2022) administered standardized reading assessments (Test of Word Reading Efficiency Second Edition, TOWRE 2; Torgesen et al., 2012; Word Attack, Word Identification, Passage Comprehension, Woodcock Reading Mastery Tests; Woodcock, 2011) over a videoconferencing platform after a year-long reading intervention. The assessments took place at school and were facilitated by a teacher, but the assessments were administered remotely by the researchers (i.e. child saw test items on their screen while the experimenter scored children's responses in accordance with the test protocols). The authors emphasized the need for individuals to be present to assist children as needed (Hodge et al., 2022).

Although smartphone-, tablet-based, or videoconferencing assessments have become increasingly widespread, there is a need for low-cost assessments using simple phones in low-resource settings, particularly in LMICs. Assessing children's language and literacy skills via simple phone introduces additional challenges. Using a phone to assess language and literacy requires that the child understands how to use the technology, can hear any instructions and test items, and completes an assessment without scaffolding from a parent or older sibling. Literary assessments specifically require a child to read visual stimuli (i.e., read a list of words, read a

passage), which are particularly challenging to administer using a simple phone relative to numeracy assessments (Angrist et al., 2020a; Joshi & Sudhanshu, 2021; Khurana, Kruske, et al., 2022; Khurana, Levin, et al., 2022; Koomar & Blest, 2020).

For example, Saarthi Education conducted a phone-based assessment of early grade numeracy skills of over 300 students aged two to 11 years in New Delhi, India (Joshi & Sudhanshu, 2021). Participating families received a call from a trained enumerator, who after obtaining consent, would ask the parent to pass the phone to their child for the assessment. Children's numeracy skills were assessed orally, and the researchers opted to exclude literacy assessments due to the challenges of incorporating visual stimuli (Jhingran et al., 2021). Similarly, in October 2020, a pilot program in Ghana explored the logistical and technological feasibility of phone-based (using SMS, interactive voice response [IVR], and live phone calls [LPC]) numeracy assessment for primary-school students. The program was expanded to Nepal and Pakistan in July 2021, and added literacy assessment in Nepal (Khurana, Levin, et al., 2022; Radhakrishnan et al., 2021). Children's level of engagement with phone-based assessments varied, but as many as ~50%-75% of participants completed the assessment, indicating that the simple phone assessment was effective (Khurana, Levin, et al., 2022).

Angrist and colleagues (2020a) also explored the feasibility of conducting phone-based assessments with children in a pilot project in Botswana. The authors compare a numeracy assessment completed by participants face-to-face prior to COVID-19-related school closures, and the same assessment completed via phone with the same participants before school closure. Angrist and colleagues (2020a) administered a phone-based numeracy assessment to 2,250 third- and fifth-grade children. Members of the research team would call the children and, after asking for consent from parents/guardians, would ask the children a series of numeracy questions

ordered in terms of operational difficulty (e.g., addition → subtraction → multiplication → division). Children would also receive a text message with a word problem that they were required to complete in a maximum time of two minutes. Children had to explain their work to the experimenter via phone call. By comparing the percentage of children who achieved higher operational difficulty (e.g., percentage of students able to complete multiplication and division questions) in the in-person testing versus the phone-based testing, Angrist et al. (2020a) concluded that the phone-based numeracy assessment was as effective as the in-person numeracy assessment (Angrist et al., 2020a). Their work provides key insights on the practicality of the usage of mobile phones in learning assessments for research; including tips and lessons on mobile phone usage for testing: (1) testing the reliability and validity of the measure being used, (2) keeping the questions and instructions simple, and (3) remembering that some assessments will work better as “phone assessments” while others may not.

Whether language and literacy assessments are conducted in-person or remotely, assessments need to be reliable and valid. The current study expands on Angrist et al. 's (2020a) recommendation for phone-based learning assessments and provides first-time evidence on the reliability and validity of a phone-based language and literacy assessment. Reliability, the consistency of measurement, can be established across researchers (inter-rater), across items (internal consistency), and over time (test-retest). Validity, whether the assessment measures the target construct, can be established based on a criterion (whether scores on a new measure are correlated with an established measure of construct of interest), content (whether a measure covers the construct of interest), discriminability (whether scores on a new measure are not correlated with an established measure of an unrelated construct), as well as face value (whether a new measure appears to measure a construct of interest). More specifically, criterion validity

involves concurrent (whether scores on a new measure are correlated with another concurrent outcome), predictive (whether scores on a new measure predict a future outcome), or convergent (whether scores on a new measure are correlated with scores on an established measure of a construct of interest). However, to the best of our knowledge, no studies to date report the reliability and validity of phone-based language and literacy assessments.

Côte d'Ivoire

In this study, we focused on rural Côte d'Ivoire, where the youth (15-24 years) literacy rate is approximately 58% (UNESCO Institute for Statistics, 2019), mobile-phone penetration rates are high (GSMA, 2017), and COVID-19-related school closures have limited in-person education research. Ivorian schools closed their doors to in-person learning on March 16, 2020, affecting 7 million children including preschool, primary, general and technical secondary, and vocational training students¹. The impact of COVID-19-related school closures on in-person education research spurred a widespread and immediate need to develop remote research methods to assess children's learning. The use of low-cost simple mobile phones for remote data collection is a particularly compelling approach for education research in low-resource communities, where cost barriers may prevent potential participants from participating in research using smartphones, tablets, or computers.

Telecommunications Infrastructure and Mobile Technology Use in Côte d'Ivoire

Mobile-phone usage in Côte d'Ivoire is widespread; mobile phone penetration (i.e., active number of mobile phones/people) in Côte d'Ivoire is 122%; some individuals have more than one active mobile phone (GSMA, 2017). However, only 46% of the Ivorian population has a

¹ Schools reopened on May 18, 2020 in the interior of the country, and on May 25, 2020 in Abidjan by special provision.

mobile internet subscription. This means the number of people in Côte d'Ivoire that have access to an active SIM card far exceeds the number of people who have access to the internet. There is also a large divide between smartphone and simple phone usage: 39% of the population in Côte d'Ivoire uses smartphones, whereas over 80% of the population uses simple phones (GSMA, 2017). Of the smartphone users in Côte d'Ivoire, 69% use mobile internet, compared to only 27% of simple phone users. Furthermore, large urban versus rural disparities in technology use exist for smartphones (57.6% for urban vs. 45% for rural areas), simple phone (93% for urban vs. 71% for rural) as well as computer ownership (8% for urban vs. <1% for rural; (Chéneau-Loquay, 2012; INS, 2018; INS, 2013).

Smartphones cost more than simple phones, hence the use of simple phones is more widespread in impoverished rural communities. A simple phone can be purchased for approximately 8,000 CFA (approximately \$14 USD), whereas a smartphone costs at least 25,000 CFA (approximately \$44 USD). The cost difference is important when considering that 46.3% of Ivorians live below the national poverty line (World Bank, 2021). With over 50% of the population not connected to mobile internet, smartphone assessments that rely on an internet connection are not a viable tool for remote data collection that aims to reach more vulnerable children in low-resource and rural communities.

Current Study

In the current longitudinal study, we developed and deployed a low-tech phone-based language and literacy assessment for primary-school children in Côte d'Ivoire participating in an ongoing literacy intervention study (Madaio et al., 2019a; Madaio et al., 2019b; Madaio et al., 2020a; Madaio et al., 2020b). We used voice calls and SMS messaging to measure language skills (phonological awareness, vocabulary, oral language comprehension) and literacy skills

(letter identification, word and pseudoword reading, passage reading and comprehension). We assessed children's PA abilities using an initial phoneme deletion task (i.e., say 'cat' without the /k/), vocabulary abilities using an antonym generation task (i.e., big-small), language comprehension abilities with a series of comprehension questions about an orally recounted story, and reading abilities with letter, word, and pseudoword reading, and passage reading and comprehension tasks. Each child completed this assessment at three-timepoints (in-person baseline, phone-based midline, in-person endline). We address the following research questions:

- 1) Is a phone-based language and literacy assessment reliable and valid?
- 2) How does a phone-based assessment compare to an in-person language and literacy assessment?

To answer these research questions, we first measured reliability by calculating internal consistency (Cronbach's alpha and inter-item correlations) for each phone-based language and literacy subtest (phonological awareness, vocabulary, oral language comprehension, letter identification, word and pseudoword reading, and passage reading and comprehension). We then compared internal consistency between in-person and phone-based versions of the same tasks administered to the same child. First, we predicted that if the phone-based assessment is reliable overall, then measures of internal consistency should be high across all language and literacy subtests (Cronbach's alpha score of .70 or higher). Second, we predicted that if the phone-based assessment is as reliable as the in-person assessment, then measures of internal consistency should be similarly high for the in-person baseline, phone-based midline, and in-person endline timepoints. Finally, we took a more nuanced approach by comparing reliability across socioeconomic and gender sub-groups. We know that literacy rates vary based on socioeconomic

status and gender, and wanted to ensure that the reliability was consistent across groups. Here, we predicted that measures of internal consistency would be similarly high across subgroups.

Next, we measured validity by comparing how children's scores on phone-based and in-person measures were correlated. To establish concurrent criterion validity, we tested whether scores on each sub-test were correlated with other concurrent outcomes. Given that phonological awareness and vocabulary are both important and well-established predictors of decoding ability (Goswami & Bryant, 1990; Hulme, 2002; Jasińska & Petitto, 2018; Wagner & Torgesen, 1987), we predicted that children's phonological awareness scores and vocabulary scores would be significantly correlated with letter, word, and pseudoword reading. Similarly, oral language comprehension and pseudoword decoding are both important and well-established predictors of reading comprehension (Gough & Tunmer, 1986; Ryherd et al., 2018), and we predicted that children's oral language comprehension and pseudoword reading scores would be significantly correlated with passage reading and passage comprehension scores.

To establish predictive criterion validity, we tested whether scores on each sub-test were predictive of future language and literacy outcomes (measured at later timepoints). If the phone-based assessment is a valid measure of language and literacy skills, then we predicted that (1) children's scores on the in-person language and literacy assessment (baseline) would predict future language and reading outcomes measured by phone (midline), and (2) children's scores on the phone-based language and literacy assessment (midline) would predict future language and reading outcomes (endline).

In low-resource settings where individuals do not have access to costly devices, data, or internet subscriptions, low-cost technologies offer education researchers the potential to conduct remote language and literacy assessments. Participants from remote or low-resource areas are

more likely to be reached through phone-based research methods, increasing the participation of underrepresented populations in research. However, limited information exists about phone-based research methods to assess children's learning, particularly in low-resource communities, and even less is known about whether such phone-based remote research methods are reliable and valid. Insights gained from this study can support education research in rural communities in LMICs, both during school closures and beyond, and may also provide alternative testing methods suitable for both high- and low-resource areas of HICs.

Methods

Participants

685 children ($N_{\text{male}}=347$) between the ages of 8 and 16 ($M_{\text{age}}=10.68$ years, $SD_{\text{age}}=1.41$ years) participated in this longitudinal study. The children were recruited from 32 schools in 8 villages in the Adzopé region of Côte d'Ivoire. Children, who were in fifth grade (CM1 in the French education system), were a part of an ongoing literacy intervention study in rural Côte d'Ivoire. The same group of children were tested at three timepoints. Time 1: in-person at baseline (pre-pandemic in October-November 2019); Time 2: by phone at midline (November 2020); and Time 3: in-person at endline (April-May 2021). At baseline, 1195 children participated, at midline, 697 children participated, and at endline, 975 children participated. At endline, about 10% of children had dropped out of school (see Wortsman et al., under review), moved away ($N=43$), were absent on the day of data collection ($N=79$), had died ($N=3$), or the child's status was unknown ($N=19$). 62 children were missing data at one timepoint and an additional 58 children were missing at least one measure and were further excluded from analyses. Our analyses only compared children with complete data at baseline, midline, and

endline ($N=565$; $N_{\text{male}}=284$; $M_{\text{age}}=10.59$ years, $SD_{\text{age}}=1.40$ years); of this sample, 493 children or 87% had advanced to 6th grade, and 69 children or 12% were repeating the 5th grade).

Exclusion criteria. Children with mental and/or physical disabilities, such as Autism Spectrum Disorder, Down Syndrome, blind, deaf or hard-of-hearing were not eligible for the study. No children were excluded based on these criteria.

The study received ethical approval from the Ivorian Ministry of Education and the University of Toronto and the University of Delaware research ethics boards. After obtaining government and ethical approval, the research team obtained approval from community leaders (village chiefs, school directors, and a parent-teacher representative group (*comités de gestion des établissements scolaires* [COGES]; the management committees of the schools).

Measures

Background Questionnaire

Children completed interviews asking about their demographics (e.g., age, grade, languages spoken at home) and household inventory (e.g., radio, refrigerator, bicycle, etc.), which was used as a proxy for socioeconomic status (SES) score and was calculated for each child by summing the number of items they reported having in their home. We adapted questionnaire items from the Bilingual Language Background and Use Questionnaire (Berens et al., 2013; Jasińska & Petitto, 2013, 2014, 2018) and the USAID Early Grade Reading Assessment (EGRA) Child Questionnaire (RTI International, 2015).

In-Person Language Measures

Children completed phonological awareness and oral language comprehension tasks based on Bruce (1964) and the French version of the Early Grade Reading Assessment (EGRA) previously used in Senegal and Mali (Dubeck & Gove, 2015; Gove & Wetterberg, 2011; RTI

International, 2015); no Ivorian French EGRA existed at the time of data collection. A group of native Ivorian French-speaking linguists and education researchers confirmed that the French EGRA was appropriate for this context. Children also completed French vocabulary tasks adapted from the Language Proficiency Battery of the Woodcock-Johnson III (Woodcock et al., 2001); as such, basal and ceiling rules were not followed. We specifically avoided using a picture-based vocabulary task, as images can often be strongly culturally-bound and therefore inappropriate for rural Ivorian context. Notably, all in-person measures were previously implemented in Côte d'Ivoire to assess the language and literacy skills of children in this age range (Akpé et al., 2021; Ball et al., 2022; Jasińska, Akpé, et al., 2022; Jasińska, Zinszer, et al., 2022; Wortsman et al., under review; Zinszer et al., 2020).

Phonological awareness. Children completed an initial phoneme deletion task. Children were given 10 common French words and were asked to repeat a word that they heard while identifying and omitting the initial phoneme (e.g., *pelle* - /p/ = /elle/; Bruce, 1964).

Vocabulary. Children completed an antonym generation task translated from WJ-III-COG (Woodcock, McGrew, & Mather, 2001). Children were given ten common French words and were asked to provide an antonym (e.g. *gauche* [left] and *droit* [right]).

Oral Language Comprehension. Children were asked to respond to comprehension questions after a native Ivorian French-speaking experimenter read aloud a passage that described an action or story which was contextually familiar to the child and was approximately 45 words long (Dubeck & Gove, 2015; Gove & Wetterberg, 2011; RTI International, 2015).

In-Person Literacy Measures

Children completed timed letter, word, pseudoword, and passage reading tasks from the French version of the EGRA (Dubeck & Gove, 2015; Gove & Wetterberg, 2011; RTI

International, 2015). For each task, children first completed a practice round with scaffolding and feedback provided by the experimenter. Children had 60 seconds to complete each task.

Experimenters marked incorrect items. Each task was terminated if 60 seconds elapsed, or the child could not read the first ten items.

Letter Reading. Children were asked to read 100 letters and letter combinations (e.g., ‘ou’). Critically, this is a test of letter sound knowledge not letter naming. Each letter or combination was used only once, and all items were frequently used in Ivorian French.

Word Reading. Children were asked to read a list of 50 familiar French words (e.g., ‘papa’, ‘carte’).

Pseudoword Reading. The pseudoword reading task assesses a child’s ability to decode novel words. Children were asked to read a list of 50 mono- or bisyllabic words that conformed to French syllabic and phonotactic structure, but do not exist in French (e.g., ‘toche’, ‘donré’).

Passage Reading and Comprehension. Children were asked to read a culturally appropriate passage out loud while the experimenter noted incorrect items to assess passage reading. The passage reading task was scored as the number of correctly read words in 60 seconds. Afterwards, children were asked five questions about the passage to assess comprehension. The passage comprehension task was scored as the number of correctly answered questions. Passage reading and passage comprehension are analyzed separately.

Phone-Based Language Measures

We developed a version of the above in-person language and literacy assessment to be delivered through a simple phone (see Figure 1 for pictures of the simple phone).

Children completed phonological awareness, vocabulary and oral language comprehension tasks identical to those in the in-person assessment. For phonological awareness,

children completed an initial phoneme deletion task where they were asked to repeat a word they heard over the phone while omitting the initial phoneme (10 items). For the vocabulary task, antonym generation, children were also asked to provide the antonym of a word they heard over the phone (10 items). Lastly, the oral language comprehension task required children to answer comprehension questions after an Ivorian French-speaking experimenter read a passage aloud from the French EGRA over the phone.

Phone-Based Literacy Measures

As with our in-person assessment, children completed the same timed letter (100 item), word (50 item), pseudoword (50 item) reading, and passage reading and comprehension tasks over the phone. Children had 60 seconds to complete each task. For each task, children first completed a practice round with scaffolding and feedback provided by the experimenter.

Figure 1

Itel it5260 Model Mobile Phone Used for the Language and Literacy Assessment

Note. (A) and (B) shows the on-screen text on the phone which contains items from the letter reading identification task. (C) and (D) shows the on-screen text for the word reading task. (E) shows the on-screen text for some of the items in the pseudoword reading task. (F) shows the first message received for the passage reading task.

Procedure

In-Person Assessment

Children completed interviews and in-person assessments one-on-one with a trained experimenter during school hours in the school's outdoor courtyard or empty classroom. All experimenters were native speakers of Ivorian French and a local language, who had at least an undergraduate degree in a relevant field (psychology, education, linguistics, sociology). The language and literacy assessment lasted approximately 30 minutes. Children received a small gift (e.g., a book or other school supplies) upon completion of the assessments. Community-level consent and child assent was obtained prior to testing. Please see Jasińska and Guei (2018) for a detailed description of culturally-relevant oral and community consent procedures developed for the study context.

Phone Assessment Development

Development. A research team of Ivorian and North American researchers in child development and education developed the phone-based assessment. The research team was already familiar with in-person language and literacy assessments (i.e. EGRA). The research team reviewed existing assessments that were previously used in Côte d'Ivoire to measure children's language and literacy development (e.g. Ball et al., 2022) and determined which subtests would be best suited to be carried out via simple mobile phone. Several criteria guided the choice of items used in the phone-based assessment. First, the research team established a 30-minute maximum length of time for testing. During the piloting phase, children's performance became noticeably poorer after 30 minutes of testing (e.g. children became restless). Second, the assessment needed to measure key language skills that are relevant to reading, as well as a range of reading skills. Phonological awareness and vocabulary measures

were included given the robust link between these language skills and decoding ability (Wagner et al., 1997), and oral language comprehension measures were included given the robust link between language comprehension and reading comprehension (Gough & Tunmer, 1986). Lastly, literacy measures were selected to correspond to a range of literacy skills: from letter-sound identification, word and pseudoword decoding, and reading comprehension. The tasks chosen for the phone assessment were the same as the tasks chosen for the in-person assessments.

Research assistants were trained by experienced researchers and were therefore well-prepared to perform the assessments. The team previously acquired theoretical training in language and literacy development and psychological assessment (e.g., literature reviews, training seminars, conference attendance). The team then received practical training in child assessment and data collection (e.g., hands-on practice sessions of the phone-based assessment with each team member) in Abidjan between September and November 2020.

Pilot. The research team piloted the phone-based language and literacy assessment in September of 2020. The goals of this pilot phase were to determine if the phone-based assessment was feasible for a child to complete and whether the regional telecom infrastructure would support phone calls with SMS messaging for the full test length without dropped calls or insufficient audio quality to administer the assessment. The pilot test was carried out in the child's home in the rural community of Adzopé with a local research assistant who had been previously trained in administering the protocol. 12 children participated in this pilot. This research assistant remained on-site to facilitate piloting but did not administer the assessment. The local research assistant introduced the study to the parent and child and provided a basic phone (Itel model it5260 phone, Itel Inc.) for the duration of the session. A second off-site research assistant called the test site. When the phone rang, the child's parent or guardian would

have to answer the phone. At this point, the off-site research assistant explained the purpose of the study in order to obtain parental consent to continue. Once the parent consented to participate in the study, the off-site research assistant asked the parent to hand the phone to their child. The off-site research assistant explained the study to the child and after child assent was obtained, the off-site research assistant would continue the pilot testing. The on-site research assistant documented the implementation of the protocol.

The pilot testing allowed us to establish that phone calls and SMS text messages were a feasible and convenient way to reach children. Over the course of the pilot tests, we observed children becoming familiar with reading the on-screen text and handling the phone, indicating they were able to complete the assessment tasks. The children were able to use the phone in speaker mode or use headphones to listen to the call during the assessment.

The phone-based assessment was also successful with respect to costs and time; costs associated with data collection were greatly reduced; travel expenses and travel time and set-up on site were reduced. The assessment depended on a stable telecommunication network connection and any momentary interruptions (e.g., fluctuation or variation in speed of text message delivery) could be disruptive to the test. The on-site research assistant was therefore valuable to assist if such cases arose.

However, difficulties experienced during this pilot phase influenced the final protocol. When children completed the phone-based assessment at home, they experienced distracting background noise, and interference from siblings and/or parents/guardians. To maintain the same testing contexts the same between the in-person assessment and the phone-based assessment, final phone-based testing was conducted at the child's school, rather than at home, once the schools had resumed in-person learning. Since the goal of this study was to determine whether

phone-based assessments are comparable to in-person assessments, particularly whether they are reliable and valid measurements of children's language and literacy skills, it was important to keep the testing contexts as similar as possible to appropriately compare the assessment conditions (i.e., phone-based versus in-person). See the discussion section for further explanation as to why children were not tested at home.

Phone Assessment Implementation

Although schools had reopened, travel between the city of Abidjan and the interior of the country was limited due to restrictions on entering and leaving Abidjan. Individuals needed to obtain authorization from the authorities before travelling outside of Abidjan. This was the country's policy to safeguard the interior of Côte d'Ivoire, which on April 21, 2020 had not recorded any cases of COVID-19. At the same time, the need to adhere to COVID-19 protocols limited the ability of the Abidjan-based research team to visit school sites in the interior. Therefore, a small team of four on-site research assistants who lived in the participating communities facilitated the phone-based assessments, while a larger team of 14 off-site Abidjan-based researchers (who were restricted in travel) administered the assessments by phone. The on-site research assistant provided a simple mobile phone to the child for the duration of the assessment (Itel model it5260 phone, Itel Inc.). Children completed phone-based assessments one-on-one with a trained off-site research assistant through a simple mobile phone. Testing was done with the phone in speaker mode or with the child wearing earphones, see Figure 2. The off-site research assistant was required to go through preliminary questions with the child before starting the assessment. These questions included asking the child to make sure the mobile phone is charged (to mitigate against the risk of it turning off during the assessment), asking if they were in a quiet area, asking if they could hear the research assistant clearly, and

guiding them through a series of steps to ensure they can manipulate the phone properly and read the on-screen text.

Figure 2

Phone Assessment

Note. (A) Child completing the assessment at home (B) Child completing the assessment at school.

Each testing session lasted approximately 30 minutes. For the language subtests, the research assistant provided verbal instructions to the child and recorded their responses. For the literacy assessment, the experimenter sent SMS messages to children for each subtest and asked the child to read the contents of the message. In total, children received eight messages, see Figure 1. The subtests were divided into separate messages to ensure that the message's contents fit on the phone screen. For the passage comprehension subtest, the experimenter asked the child questions about the passage they had read. The off-site research assistants administering the assessment to children remotely used a basic telephone (identical model to the phone used by the children). Testing took place in a quiet environment (i.e., in a quiet corner of the school yard), ensuring that the testing environment did not impact the quality of the responses. Overall,

children showed a generally relaxed attitude, were attentive to the tests and answered the research assistant's questions. Children were already familiar with the contents of the assessment administered by phone as they had previously completed the same battery in-person during baseline.

Of the 697 children who started the assessment over the phone, 692 completed all subtests. 0.71% stopped testing for two main reasons. First, some children had difficulty following instructions over the phone and did not complete the task, and second, technical problems related to the stability of the network and the sound quality of the call.

All data were collected and stored using REDCap (Research Electronic Data Capture) a secure, web-based data collection and storage platform (Harris et al., 2019; Harris et al., 2009).

Data Analysis

Data analysis was conducted in R (The R Core Team, 2016). To establish assessment reliability, we first calculated Cronbach's alpha and inter-item correlations using the 'psych' Rstudio package (Revelle, 2019). We conducted t-tests to compare Cronbach's alpha coefficients for in-person versus the phone-based assessments using the 'cocron' package (Diedenhofen & Musch, 2016). The 'cocron' package was also used to compare Cronbach's alpha coefficients for reliability subgroup analyses. Mean inter-item correlations, correlations between the items of both the in-person and the phone assessment, were calculated to determine the extent of the relationship between scores on the various items using the 'corr' package (Kuhn et al., 2020). Correlation coefficients were compared across in-person and phone-based assessments using the paired.r function in the 'psych' package.

To establish assessment validity, we conducted regressions and correlations using 'lm' and 'cor.test' packages (The R Core Team, 2016), respectively. We first performed correlations

between all measures, and between each measure at every timepoint. Correlation tables were generated using the ‘apaTables’ (Stanley & Spence, 2018) package. Second, we performed regression analyses to test whether phonological awareness and vocabulary scores predicted letter, word, and pseudoword reading scores, as well as regression analyses to test whether oral language comprehension, pseudoword reading, passage reading and comprehension scores for in-person and phone-based assessments at each timepoint (both concurrent, and predictive). Lastly, we performed floor and ceiling calculations to determine the frequency of the lowest and highest scores for each subtest at each timepoint, across four different age quartiles.

Results

Figure 3 shows mean scores for each task at each timepoint. Performance on each task shows improvement at each subsequent timepoint (children were tested at baseline at the start of the academic school year, midline one year later, and endline was collected at the end of the second academic).

Figure 3

Percent Correct Scores for each Language and Literacy Test Administered at Baseline (in-person), Midline (phone-based), and Endline (in-person).

Reliability

Cronbach's Alpha and Inter-Item Correlation

Overall, there was acceptable to high internal consistency, as indicated by Cronbach's alpha, for all measures of the phone-based assessment (ranging from 0.701 to 0.958), except for the oral language comprehension (0.561, see Table 1). Cronbach's alpha values above 0.70 represent an acceptable internal consistency (Forero, 2014). Similarly, there was acceptable to high internal consistency for the in-person measures, both at baseline and endline, except antonym generation (0.63 and 0.677, respectively), oral language comprehension (0.535 and 0.476) and passage comprehension questions (0.574 and 0.513). Baseline and endline in-person measures showed significantly higher internal consistency for phonological awareness, word

reading (endline only), pseudoword reading, and passage reading measures (baseline only), however, phone-based measures showed significantly higher internal consistency for antonym generation and letter reading.

Mean inter-item correlations ranged from 0.078 to 0.417 for all measures, and were generally higher for phonological awareness, antonym generation, and oral language and passage comprehension measures, and generally did not differ statistically across in-person and phone-based tasks with the exception of initial phoneme deletion (higher inter-item correlation for in-person endline versus phone-based midline, and for phone-based midline versus in-person endline for passage comprehension), see Table 1.

Reliability across Subgroups

We further analyzed whether reliability of the phone assessment differed across two important demographics (gender and socioeconomic status) in our sample. Socioeconomic status groups were based on median group split with 49% and 51% of the sample in low and high socioeconomic status groups, respectively. The results of these analyses are in Supplementary Materials Tables 1 and 2. We found no significant differences in reliability based on gender for phonological awareness, antonym generation, oral language comprehension, or pseudoword reading, passage reading, or passage comprehension. For letter reading, reliability was significantly greater for girls than boys. Notably, however, both groups still had high reliability (Cronbach's alpha greater than 0.70) for all tasks apart from oral comprehension and passage comprehension, which had few test items.

We found no significant differences in reliability between socioeconomic status groups for phonological awareness, antonym generation, oral language comprehension, word reading, or passage comprehension. Cronbach's alphas were higher for higher SES children for letter and

pseudoword reading tasks, but lower for passage reading. Both groups had high reliability (Cronbach's alpha greater than 0.70) for all tasks apart from oral comprehension, which had few test items.

Validity

Criterion Validity

In-person (both at baseline and at endline), and phone-based measures were all moderately to strongly correlated ($r=.35-.83$; $p<.01$ for all measures; see Table 2). Reading measures (letter, word, pseudoword, passage reading, passage comprehension) were more strongly correlated ($r=.57-.80$) compared with language measures (phonological awareness, vocabulary, oral language comprehension; ($r=.35-.62$), see Table 2.

Table 1*Cronbach's Alpha, Inter-item Means, and Statistical Comparisons for In-person and Phone-based Tasks*

Tasks	Average Inter-Item Correlation			Comparison of Correlation Coefficient			Cronbach's Alpha			Comparison of Alpha Coefficient		
	Baseli	Midli	Endli	Baseline	Baseline	Midline	Baseli	Midli	Endli	Baseline vs.	Baseline vs.	Midline vs.
	ne (in-perso n)	ne (phone)	ne (in-pers on)	vs. Midline	vs. Endline	vs. Endline	ne (in-perso n)	ne (phone)	ne (in-pers on)	Midline	Endline	Endline
Initial Ph. Del. (10 items)	0.39	0.301	0.417	z=1.696	z=0.541	z=2.237	0.865	0.811	0.877	t(563)=4.94 3***	t(563)=1.414	t(563)=6.172 ***
Antonym s (10 items)	0.146	0.195	0.173	z=0.846	z=0.464	z=0.382	0.63	0.707	0.677	t(563)=3.04 9**	t(563)=1.731	t(563)=1.337
Oral Lg. Comp. (5 items)	0.187	0.204	0.154	z=0.296	z=0.57	z=0.866	0.535	0.561	0.476	t(563)=0.73 8	t(563)=1.513	t(563)=2.307 *
Letter Reading (100 items)	0.146	0.184	0.076	z=0.655	z=1.189	z=1.843	0.94	0.958	0.88	t(563)=5.15 8***	t(563)=10.562 ***	t(563)=16.03 4***
Word Reading (45 items)	0.082	0.099	0.107	z=0.287	z=0.423	z=0.136	0.78	0.832	0.86	t(563)=4.78 1***	t(563)=7.5***	t(563)=3.487 ***
Pseudow ord Reading (45 items)	0.136	0.098	0.123	z=0.646	z=0.222	z=0.424	0.876	0.83	0.863	t(563)=5.52* **	t(563)=1.628	t(563)=4.268 ***
Passage Reading (45 items)	0.114	0.083	0.069	z=0.525	z=0.761	z=0.236	0.85	0.803	0.75	t(563)=5.09 1***	t(563)=8.325* **	t(563)=4.377 ***

Passage	0.184	0.306	0.167	$z=1.989$	$z=0.268$	$z=2.257$	0.574	0.701	0.513	$t(469)=5.93$	$t(469)=1.89$	$t(469)=9.559$
Comp.				*		*				8***		***
(6 items)												

Note. $p<.05^*$, $p<.01^{**}$, $p<.001^{***}$

Table 2

Correlations between Baseline (in-person), Midline (phone-based), and Endline (in-person) Scores

Variable	Time	<i>M</i>	<i>SD</i>	Baseline	Midline
Initial Ph. Del.	Baseline	2.27	3.02		
	Midline	3.38	3.14	.58** [.53, .64]	
	Endline	4.76	3.77	.62** [.57, .67]	.55** [.49, .61]
Antonyms	Baseline	1.9	2.3		
	Midline	3.41	2.79	.41** [.34, .48]	
	Endline	5.59	2.49	.36** [.29, .43]	.50** [.44, .56]
Oral Lg. Comp.	Baseline	3.22	1.32		
	Midline	3.39	1.35	.38** [.31, .45]	
	Endline	4.03	1.08	.35** [.27, .42]	.41** [.34, .48]
Letter Reading	Baseline	24.5	19.32		
	Midline	37.51	22.42	.57** [.51, .62]	
	Endline	54.1	23.64	.61** [.55, .66]	.58** [.53, .63]
Word Reading	Baseline	11.47	14.23		
	Midline	21.08	15.61	.74** [.70, .78]	
	Endline	28.15	17.02	.69** [.65, .73]	.78** [.75, .81]
Pseudoword Reading	Baseline	7.84	11.24		
	Midline	17.19	15.73	.73** [.69, .77]	
	Endline	23.39	16.82	.69** [.64, .73]	.80** [.77, .83]
Passage Reading	Baseline	14.51	17.6		
	Midline	19.26	19.21	.77** [.73, .80]	
	Endline	24.89	19.82	.68** [.63, .72]	.76** [.73, .79]
Passage Comp.	Baseline	1.01	1.87		
	Midline	2.08	2.36	.76** [.72, .80]	
	Endline	2.6	2.54	.64** [.59, .69]	.83** [.80, .85]

Note. $p < .05^*$, $p < .01^{**}$, $p < .001^{***}$

Predictive Validity

Phonological awareness and vocabulary significantly predicted both in-person and phone-based letter, word, and pseudoword reading scores at each timepoint (all measures $p < .001$, except endline vocabulary did not significantly predict endline reading; see Table 3).

Phonological awareness was a stronger predictor of reading (std. beta coefficients ranged from 0.387-0.712) compared to vocabulary (std. beta coefficients ranged from 0.06-0.186), and all

models explained between 20-50% of the variance in reading scores (R^2 ranged from 0.208 - 0.546). Pseudoword reading and oral language comprehension significantly predicted both in-person and phone-based passage reading and comprehension scores, see Table 4. Pseudoword reading was a stronger predictor of passage reading and comprehension (std. beta coefficients ranged from 0.551-0.868) compared to oral language comprehension (std. beta coefficients ranged from 0.067-0.139), and all models explained between 30-70% of the variance in reading scores (R^2 ranged from 0.329-0.779).

Table 3*Regression Models for In-person and Phone-based Letter, Word, and Pseudoword Measures*

Time	Variable	Letter Reading			Word Reading			Pseudoword Reading		
		Baseline (in-person)	Midline (phone)	Endline (in-person)	Baseline (in-person)	Midline (phone)	Endline (in-person)	Baseline (in-person)	Midline (phone)	Endline (in-person)
		b(SE)	b(SE)	b(SE)	b(SE)	b(SE)	b(SE)	b(SE)	b(SE)	b(SE)
Baseline	Initial Ph. Del.	3.832(0.215) ***	3.008(0.294) ***	3.347(0.308) ***	3.349(0.141) ***	2.675(0.19)* **	2.813(0.212) ***	2.61(0.112)* **	2.771(0.188) ***	2.941(0.205) ***
	Antony ms	1.122(0.282) ***	1.117(0.386) **	1.001(0.404) *	0.452(0.186) *	0.764(0.249) **	0.662(0.278) *	0.436(0.147) **	0.819(0.247) ***	0.672(0.269) *
	R ²	0.43	0.208	0.22	0.546	0.32	0.287	0.542	0.34	0.32
Midline	Initial Ph. Del.	NA	2.854(0.292) ***	2.905(0.316) ***	NA	2.49(0.197)* **	2.509(0.22)* **	NA	2.464(0.196) ***	2.755(0.214) ***
	Antony ms	NA	1.493(0.329) ***	1.305(0.355) ***	NA	0.604(0.221) **	0.678(0.248) **	NA	0.799(0.221) ***	0.364(0.241)
	R ²	NA	0.265	0.229	NA	0.315	0.276	NA	0.329	0.298
Endline	Initial Ph. Del.	NA	NA	3.299(0.254) ***	NA	NA	3.124(0.159) ***	NA	NA	3.022(0.16)* **
	Antony ms	NA	NA	-0.114(0.385))	NA	NA	-0.303(0.24))	NA	NA	-0.32(0.242)
	R ²	NA	NA	0.271	NA	NA	0.452	NA	NA	0.431

Table 4*Regression Models for In-person and Phone-based Passage Reading and Comprehension Measures*

Time	Variable	Passage Reading			Passage Comprehension		
		Baseline (in-person)	Midline (phone)	Endline (in-person)	Baseline (in-person)	Midline (phone)	Endline (in-person)
		b(SE)	b(SE)	b(SE)	b(SE)	b(SE)	b(SE)
Baseline	Pseudoword Reading	1.331(0.035)***	1.124(0.055)***	0.972(0.063)***	0.152(0.004)***	0.151(0.006)***	0.14(0.008)***
	Oral Lg. Comp.	0.336(0.3)	0.975(0.466)*	1.08(0.535)*	0.031(0.031)	0.15(0.053)**	0.212(0.064)***
	R ²	0.735	0.46	0.329	0.779	0.56	0.432
Midline	Pseudoword Reading	NA	1.061(0.025)***	0.927(0.037)***	NA	0.117(0.004)***	0.121(0.005)***
	Oral Lg. Comp.	NA	0.515(0.296)	-0.324(0.433)	NA	0.173(0.045)***	0.122(0.053)*
	R ²	NA	0.768	0.534	NA	0.661	0.589
Endline	Pseudoword Reading	NA	NA	0.996(0.027)***	NA	NA	0.118(0.004)***
	Oral Lg. Comp.	NA	NA	0.437(0.414)	NA	NA	0.323(0.058)***
	R ²	NA	NA	0.722	NA	NA	0.672

Ceiling and Floor Effects

Floor and ceiling effects were calculated by observing the frequency of the lowest and highest scores obtained by children, split by age quartile, across all measures, see Table 5. Large floor effects (>15%) were observed for in-person baseline and phone-based midline assessments of phonological awareness, antonym generation, and word reading. Floor effects were also high for in-person baseline and endline, and phone-based assessments of pseudoword reading, and passage reading and comprehension. Large ceiling effects (>15%) were observed for phonological awareness (in-person endline), oral language comprehension (all timepoints), and passage reading (all timepoints) and passage comprehension (phone-based midline, in-person endline).

Although all the children in this sample are in the same grade, there is variation in their ages. Looking at floor and ceiling effects by age quartile allows us to examine the suitability of these measures for children of varying ages. In Table 5, we see that all measures (with the exceptions of letter reading and oral comprehension), floor effects are largest for children in the highest age quartile, across all three timepoints. There is a similar trend for ceiling effects in that for many measures they have the lowest ceiling effects.

Table 5*Floor and Ceiling Effects for the In-person and Phone-based Assessments.*

Task	Age Quartile	Floor (%)			Ceiling (%)		
		Baseline (in-person)	Midline (phone)	Endline (in-person)	Baseline (in-person)	Midline (phone)	Endline (in-person)
Phoneme Deletion	1 (ages 6-9)	41.59	21.58	15.83	5.04	14.39	26.62
	2 (age 10)	39.86	23.19	18.12	5.07	4.35	18.84
	3 (ages 11-12)	39.13	23.91	18.84	3.62	4.35	18.12
	4 (age 13-16)	48.55	25.36	22.46	1.45	2.9	5.8
Antonyms	1 (ages 6-9)	40.29	25.9	10.79	0	0.72	4.32
	2 (age 10)	48.55	25.36	5.8	0	0.72	1.45
	3 (ages 11-12)	49.28	28.99	5.8	0	0	2.17
	4 (age 13-16)	52.9	29.71	13.04	0	0	2.9
Oral Comp.	1 (ages 6-9)	1.44	2.16	0.72	25.18	28.06	50.36
	2 (age 10)	1.45	2.17	0	19.57	25.36	45.65
	3 (ages 11-12)	3.62	5.8	0	22.46	15.94	41.3
	4 (age 13-16)	5.07	2.9	0	13.77	28.26	37.68
Letter Reading	1 (ages 6-9)	1.44	5.76	1.44	0	2.16	5.76
	2 (age 10)	2.17	6.52	1.45	0	2.17	2.17
	3 (ages 11-12)	0.72	7.97	5.07	0	0.72	1.45
	4 (age 13-16)	0.72	12.32	5.07	0	2.17	2.17
Word Reading	1 (ages 6-9)	17.27	16.55	9.35	1.44	17.27	1.44
	2 (age 10)	16.67	16.67	5.8	0	15.22	0.72
	3 (ages 11-12)	21.01	19.57	15.22	0	17.39	2.17
	4 (age 13-16)	30.43	29.71	21.74	0	10.14	1.45
Pseudoword Reading	1 (ages 6-9)	30.22	25.9	15.83	1.44	13.67	1.44
	2 (age 10)	34.06	30.43	14.49	0	9.42	2.9
	3 (ages 11-12)	42.03	32.61	25.36	0	7.97	1.45
	4 (age 13-16)	45.65	42.03	31.16	0	6.52	1.45
Passage Reading	1 (ages 6-9)	40.88	33.09	25.18	21.9	24.46	45.32
	2 (age 10)	44.93	36.96	26.09	16.67	10.14	44.2
	3 (ages 11-12)	54.35	40.58	34.78	15.22	13.77	37.68
	4 (age 13-16)	57.25	51.45	48.55	10.14	10.14	25.36
Passage Comp.	1 (ages 6-9)	69.49	36.92	26.67	10.17	23.85	34.81
	2 (age 10)	67.77	41.35	34.33	3.31	17.29	23.13
	3 (ages 11-12)	70.4	47.73	42.65	4.8	13.64	22.06
	4 (age 13-16)	74.42	55.3	54.74	4.65	10.61	15.33

Discussion

The goal of the current study was to assess the reliability and validity of a phone-based language and literacy assessment by comparing it to an existing in-person language and literacy assessment. Specifically, we sought to answer two research questions: (1) Is a phone-based literacy and language assessment a reliable and valid assessment? (2) How does a phone-based assessment compare to an existing in-person literacy and language assessment? Our results showed that our phone-based assessment was a reliable and valid measure of children's language and reading skills and was largely comparable to an established in-person assessment.

Reliability of a Phone-Based Language and Literacy Assessment

Cronbach's alpha and mean inter-item correlation results indicate that there was high internal consistency for both the in-person and phone-based language and literacy assessments, with the exception of oral language comprehension and passage comprehension questions, which had few test items that may have contributed to a lower Cronbach's alpha coefficients. In particular, in-person measures of phonological awareness, pseudoword, and passage reading showed significantly higher internal consistency compared to phone-based assessments, albeit phone-based measures of letter and word reading, vocabulary, and oral language comprehension showed significantly higher internal consistency. The initial phoneme deletion task may be particularly sensitive to the phone-testing context as consistent performance on this task requires a child to be able to hear the test items and the experimenter to be able to hear the child's responses. The reliability of reading tests suggests that small test items (i.e., letters) as compared to larger test items (i.e., passages) might be better administered over the phone. However, the high internal consistency of all reading measures suggests that reading tasks administered in person or by phone are reliable. We further investigated whether reliability differed based on

gender and socioeconomic status and found that overall, the phone assessment was reliable across subgroups.

Validity of a Phone-Based Language and Literacy Assessment

In-person and phone-based measures were all moderately to strongly correlated, suggesting that the phone-based measures were valid assessments of children's language and literacy skills. We found that in-person and phone-based measures of phonological awareness and vocabulary were significant predictors of children's letter, word, and pseudoword reading scores collected both in-person and by phone. We also found that in-person and phone-based measures of oral language comprehension and pseudoword reading were significant predictors of children's reading comprehension scores collected in-person and by phone.

Our results corroborate well-established findings that children's language skills (e.g., phonological awareness, vocabulary, oral language comprehension) are important predictors of reading outcomes (Goswami & Bryant, 1990; Hulme, 2002; Jasińska et al., 2019; Wagner & Torgesen, 1987). Phonological awareness is particularly important for early reading development, while children are learning to map letters to sounds in order to decode words. Vocabulary skills become more important as children gain reading experience and they can recognize a word from its written form (Anderson & Freebody, 1983; Bar-Kochva, 2013; Berends & Reitsma, 2006; Harm & Seidenberg, 2004; Jasińska et al., 2016; Jasińska & Petitto, 2018). Indeed, in this study of emergent readers, we observed stronger associations between phonological awareness and reading than between vocabulary and reading, although both phonological awareness and vocabulary were positively related to reading skills. Our findings follow the established developmental timeline of reading development.

Our results are also consistent with Gough and Tunmer's (1986) Simple View of Reading. The model posits that children's decoding skills and their language comprehension skills are crucial components of reading comprehension and support children's reading development (Gough & Tunmer, 1986). We observed that both decoding skills and language comprehension skills were predictive of reading comprehension. We are encouraged that our phone-based language and literacy assessment generated findings that corroborate the established relationships between phonological awareness, vocabulary, and children's reading skills, as well as the relationships between language comprehension, decoding, and reading comprehension.

We also observed high floor and ceiling effects across both in-person and phone-based assessments. It is important to point out that a typical classroom in Côte d'Ivoire is very heterogeneous; children of different skill levels and ages learn together. The high floor and ceiling effects would be atypical for a language and literacy assessment in a HIC context, however, it is typical in an Ivorian context. Contextual differences become more salient, when we notice that the highest floor effects are found for older children. In this sample, age does not contribute in the direction we would expect based on findings in HICs (i.e., older age is associated with higher performance), however, the findings are appropriate within this context. Despite the wide age range, all of the children within the sample are in fifth grade; those who are older are likely there due to late enrollment or grade repetition (Jasińska & Guei, 2022), both of which contribute to poorer academic outcomes (Whitehead et al., under review; Wils, 2004; Wortsman et al., under review). Importantly, high floor or ceiling effects were not exclusive to the phone-based assessment, suggesting the assessment format did not contribute to overly poor or high subtest performance.

Challenges and Opportunities of Phone-Based Language and Literacy Assessments

We were able to collect data using the phone-based language and literacy assessment from 692 out of 697 children. Children were able to receive the assessment via text messaging and phone calls and the regional telecommunications infrastructure was sufficient to support calls with minimal dropped calls and minor and infrequent technical issues. Technical issues that were observed were linked to either experimenter error (e.g., sending the wrong SMS, typing error), child usage (e.g., child accidentally ended the call), or telecommunications errors (e.g., longer duration to send/receive SMS, dropped call). While all children in this study used one specific phone model, our phone-based assessment was not designed with one model in mind, and can be administered across different devices. However, given that children in the current study were provided with the same phone model, we cannot directly conclude that the phone-assessment would be as reliable and valid if used on a different device. This could also be an area for future research in this area to explore.

The phone-based assessment protocol in the current study was developed to be administered at school with a local facilitator on-site to support data collection by an off-site research team. When first piloting the phone-based assessment in the child's home, the research team experienced challenges: there was often interference from other family members (e.g., parents or older siblings sharing test answers or coaching the participant), or the sound of music or other conversations, leading to unusable data. While we encouraged parents to avoid providing support to their child during the assessment in order to get an accurate measure of children's skills, nonetheless, our at-home protocol did not sufficiently avoid this issue. Other researchers have reported the same challenges with administering phone-based assessments (Escudero et al., 2021; Khurana, Levin, et al., 2022). For example, in Ghana, during phone

assessments, caregivers helped children by scaffolding their responses (e.g., explained the concept to the child, helped the child solve the question, reviewed the child's responses with him/her) or aiding technically (e.g., put the phone on speaker, helped child navigate the phone) (Khurana, Levin, et al., 2022). While some of these parental supports facilitate the remote assessment, others interfere with the assessment of children's true abilities. Remotely assessing young children, in particular, could result in even greater parental involvement, as young children may be even less familiar with virtual settings (Escudero et al., 2021).

Our phone-based assessment was conducted at school, rather than at the participant's home to mitigate the effects of familial interference and ensured that the data collected reflected the child's true abilities. Importantly, the same testing context applied to both the in-person and phone-based assessment, allowing us to directly compare and draw conclusions about the mode of assessment (in-person, phone-based) specifically, rather than several contextual factors (e.g., testing at school vs. home). Ultimately, while this protocol was implemented at school (once schools reopened), the insights learned from this study can inform the design of future remote data collection methods for children in different settings.

Implications

We demonstrate that low-cost simple mobile phones can provide reliable and valid assessments of children's language and literacy skills. Low-cost technologies offer significant potential to effectively measure children's language and reading skills remotely, reducing barriers to participation in research that result in unrepresentative samples, thereby achieving greater generalizability and accuracy of child learning outcomes. In-person data collection in child development and education research typically involves a researcher visiting a school or research participants visiting a laboratory. Laboratory-based research inherently creates barriers

to an inclusive science of child development (e.g., Janssen et al., 2021); for example, some participants may be unable to take time off to visit the laboratory, university campus laboratories can be unfamiliar, hard to navigate, or intimidating to visit for families who may be visiting for the first time. As a result, much of what we know about children's reading development and learning is not drawn from representative populations (e.g., Janssen et al., 2021). Remote methods have the potential to address these issues, but only if access to the technology required to participate in research is equitable.

Successful implementation of tech-based assessments in remote data collection depends on several additional factors, including (1) the infrastructure for digital communication in a given country, (2) the cost of purchasing a device and internet access borne by the participant may hinder research participation, and (3) the participants' willingness and ability to participate in research in this manner, along with the knowledge and understanding of using their mobile phones for tasks such as these (Angrist et al., 2020a; Angrist et al., 2020b; Farmer et al., 2020; Joshi & Sudhanshu, 2021; Khurana, Kruske, et al., 2022). These barriers are more prevalent in rural communities in LMICs. For example, limited internet infrastructure cannot fully support devices and applications that require a strong WiFi connection, such as Skype or Zoom. Before developing tech-based remote data collection methods, it is important to understand what technology potential participants can access and examine any assumptions that researchers might hold about a community's access to technology and willingness and ability to use technology for a specific research task. This can include beliefs about potential participants' access to WiFi, a laptop or computer, and a reliable phone, and beliefs about potential participants' willingness to use technology to share data with a research team and their technical ability to participate.

Limitations and Future Directions

A few limitations of this study should be noted. First, our phone-based data collection took place at schools with a remote off-site research team administering the assessment with support from a local on-site facilitator. A remote data collection method is better if it can reach participants in different settings (school, home). However, during the piloting phase, we found that testing children in their homes presented challenges (i.e., some children were assisted by their parents and other family members while at home or were in environments that were not conducive to testing).

Additionally, certain tasks were easier to perform over the phone than others. For example, the passage reading task was more difficult to administer over the phone. The passage that children were asked to read was divided between two messages, and children had to wait for the second part of the story to be received in a second text message; this invariably introduces additional cognitive demands for this task in particular (i.e., children need to remember the first part of the story contained in the first message while waiting for the second message). Some of the measures, including vocabulary, oral language, and passage comprehension, have relatively low Cronbach's alphas. Notably, these measures are those with the fewest of items (10, 5, and 6 items, respectively).

Finally, we note that phone-based assessments do not allow for non-verbal forms of communication or assessment that we benefit from when using alternative forms (e.g., in-person, Zoom, or Skype). Non-verbal communication allows us to probe engagement and understanding while conducting assessments in a way that cannot be achieved using phone-based assessments. Critically, we do not suggest that phone-based assessments replace other forms of assessment,

only that they are a feasible option when other assessments are not possible that allow for more inclusive and representational research.

Despite the limitations of this phone-based assessment, this study lays the groundwork for the creation of feasible, equitable, and reliable assessments for use in low-resource settings. Future studies can use the present work as a guide and explore ways to mitigate against the above limitations. Here, we conclude that phone assessments are reliable when conducted in the same context as in-person studies (i.e., at school), and importantly, were reliable for boys and girls, and for children from higher and lower socioeconomic backgrounds. However, future studies are needed to explore differences in testing children in home versus school contexts in order to better understand how to effectively conduct these assessments in the home. This would serve to expand child development and education research to children who are not attending school. Additionally, more work is still needed to address equity in assessments: future studies should examine whether the phone-based assessment is an equally valid instrument for use within additional subgroups (e.g., language status). Furthermore, it is important to note that, at present, conclusions regarding reliability and validity are limited to villages in rural Côte d'Ivoire. Future work is required to determine whether this assessment is suitable in the context of other LMICs.

Ideally, phone-based assessments could be used to expand early literacy screening in under-resourced communities. Such screeners could inform educators which students require additional support or have more widespread efficacy and inform policy change. It is our hope that phone-based assessments will continue to develop and eventually provide a cost-effective way to assess language and literacy that benefits a wide variety of stakeholders (e.g., educators, program designers, policy-makers, researchers). However, based on the limitations of the current

phone-based assessment, we call for more research into how such assessments can be feasibly used outside of the school setting or without the requirement of a facilitator prior to the widespread implementation of such tools. That said, our findings suggest that phone-based assessments have potential and warrant further research.

Conclusion

The COVID-19 pandemic has created the need for educational research to explore alternative methods of remote data collection, specifically ways in which researchers can use technology to reach a broader participant group. However, the vast majority of these methods are not equitable, and do not allow participants from low-resource and rural communities the opportunity to participate in educational research. The results of the current study show that a literacy and language assessment administered with a low-cost simple phone is a reliable and valid measure of children's abilities in comparison to an existing in-person literacy and language assessment. This has important implications in education research: low-cost remote assessments can help reduce existing barriers in data collection, such as limited access to stable internet and costly devices like smartphones and tablets. Research that uses low-cost methods for data collection increases the likelihood of obtaining a more representative sample, which is inclusive of individuals from low-resource settings and rural communities and therefore increases the generalizability of the findings.

While the COVID-19 pandemic has allowed remote data collection methods to flourish, the need for remote data collection will extend beyond the current COVID-19 pandemic. Researchers will need to continue incorporating remote data collection methods in the 'new normal' post-COVID-19 landscape. There is a need in education research for low-cost, barrier-free research methods able to reach remote, rural, and low-resource communities;

currently, this need remains largely unmet. The lessons learned through developing valid and reliable remote research methods can help shape the future of data collection in child development and education science.

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Supplementary Material

COVID19-related School Closures in Côte d'Ivoire

To limit the spread of COVID-19 in Côte d'Ivoire, the decision to temporarily close schools and technical and vocational training centers was awarded by the Ivorian National Security Council (CNS), initially for a period of 30 days from March 16, 2020, which was extended until May 17, 2020 by the Council of Ministers in its April 15, 2020 session. To reduce learning loss during school closures, the education-training sector developed a COVID-19 response plan targeting 7,054,455 students affected by school closures (Desktop review de la Côte d'Ivoire, 2021). This plan proposed strategic programming for students, particularly those who were preparing for entrance exams (i.e., children in their final year of primary and secondary school), to access inclusive and equitable distance education and training services during COVID-19 related school closures. Specifically, the Ivorian Ministry of Education made remote learning services available via the internet, television, radio, and SMS (Ministry of Education Communication, 2020). However, many students could not access educational content that required an internet connection, and students used alternative methods of learning remotely (i.e. using a mobile device) or (for many rural children) waited until schools reopened to resume learning. Mobile-based technology allows children to continue learning remotely (Kizilcec et al., 2020). The use of mobile devices for learning suggests that phone-based methods may similarly be for learning assessment.

Supplementary Table 1*Cronbach's alpha by gender*

Tasks	Females	Males	Comparison
Initial Ph. Del.	0.801	0.821	t(561)=1.112
Antonyms	0.69	0.715	t(561)=1.088
Oral Lg. Comp.	0.605	0.515	t(561)=1.228
Letter Reading	0.967	0.939	t(561)=1.848***
Word Reading	0.817	0.838	t(561)=1.13
Pseudoword Reading	0.836	0.827	t(561)=1.055
Passage Reading	0.784	0.82	t(561)=1.2
Passage Comprehension	0.72	0.686	t(561)=1.121

Note. All males answered some items incorrectly for the passage reading tasks and these items

were excluded from calculating Cronbach's alpha..

Supplementary Table 2*Cronbach's alpha by socioeconomic group*

Tasks	Low	High	Comparison
Initial Ph. Del.	0.813	0.809	$t(574)=1.021$
Antonyms	0.719	0.681	$t(574)=1.135$
Oral Lg. Comp.	0.56	0.56	$t(574)=1$
Letter Reading	0.93	0.97	$t(574)=2.333^{***}$
Word Reading	0.839	0.82	$t(574)=1.118$
Pseudoword Reading	0.785	0.874	$t(574)=1.706^{***}$
Passage Reading	0.829	0.73	$t(574)=1.579^{***}$
Passage Comprehension	0.697	0.705	$t(574)=1.027$

Note. For letter reading, word reading, pseudoword reading, and passage reading tasks, items for which all participants in a subgroup answered incorrectly were excluded from calculating Cronbach's alpha.