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Mobile technology and artificial intelligence for improving health literacy among underserved communities

Ismaila Ouédraogo

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THÈSE EN COTUTELLE PRÉSENTÉE
POUR OBTENIR LE GRADE DE

DOCTEUR DE

L'UNIVERSITÉ DE BORDEAUX

ET DE L'UNIVERSITÉ NAZI BONI

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ÉCOLE DOCTORALE SCIENCES ET TECHNIQUES (ED-ST)
SPÉCIALITÉ Mathématiques Santé publique Option Informatique et Santé
Par Ismaila, Ouédraogo

**Technologie mobile et Intelligence Artificielle pour l'amélioration de la littératie en santé dans les
milieux défavorisés**

.....

Sous la direction de Gayo DIALLO et Borlli Michel Jonas SOME
Soutenue le 14 février 2024

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Mobile Technology and Artificial Intelligence for improving health literacy among underserved communities

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Ismaila Ouédraogo

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY OF THE UNIVERSITY OF BORDEAUX AND THE
UNIVERSITY NAZI BONI

.....

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Place : Bordeaux

Date : 14/02/2024

Ismaila Ouédraogo

Résumé

Titre: Technologie mobile et Intelligence Artificielle pour l'amélioration de la littératie en santé au sein des populations défavorisées.

Résumé abrégé:

L'accessibilité et l'utilisation des informations de santé présentent effectivement des défis majeurs en Afrique subsaharienne, en particulier au sein des populations peu alphabétisées. Ces difficultés sont exacerbées par la diffusion croissante de contenus en langues étrangères dans les solutions de santé numérique, ainsi que par la conception parfois inadaptée de ces solutions pour ces populations locales. Il est impératif de tenir compte de ces facteurs lors de la conception et de la mise en œuvre de solutions de santé numériques, dans le but de les rendre véritablement accessibles et utiles à tous les segments de la population. Dans cette perspective, cette recherche adopte une approche de conception centrée sur l'utilisateur pour améliorer l'accessibilité et l'utilisation des informations de santé (littératie en santé) au sein des populations peu alphabétisées au Burkina Faso, en utilisant des solutions de santé mobiles basées sur l'intelligence artificielle. Grâce à des méthodes telles que les revues de littérature, les entretiens, les enquêtes et les observations, les besoins spécifiques des utilisateurs peu alphabétisés sont minutieusement pris en compte. En intégrant ces retours, des principes de conception concrets sont définis, guidant le développement d'un prototype de Serveur Vocal Interactif (SVI) en langue Dioula. Par la suite, l'évaluation du service mobile auprès des utilisateurs a permis d'améliorer itérativement la solution, en prenant en compte les retours des utilisateurs. De plus, cette recherche a contribué à la création d'un ensemble de données vocales annotées en Dioula, comblant ainsi le manque de données vocales pour les technologies d'assistance vocale au service des populations. En mettant l'accent sur l'importance des langues locales et des technologies adaptées, cette étude démontre comment les solutions de santé mobiles alimentées par l'IA peuvent efficacement surmonter les barrières liées à l'alphabétisation, améliorant ainsi la littératie en santé au sein des populations marginalisées. Les résultats de cette recherche s'alignent sur les objectifs de développement durable de l'ONU, renforçant ainsi leur impact positif sur la santé des populations vulnérables au Burkina Faso.

Mots-clés :

Technologie mobile, Intelligence Artificielle, littératie en santé, populations défavorisées,

Abstract

Title: Mobile Technology and Artificial Intelligence for improving health literacy among underserved communities.

Abstract :

Access and use of health information is indeed a major challenge in sub-Saharan Africa, especially for populations with low literacy. These difficulties are exacerbated by the increasing prevalence of foreign language content in digital health solutions, as well as the sometimes inadequate design of these solutions for local populations. These factors must be taken into account in the development and implementation of digital health solutions to ensure that they are truly accessible and beneficial to all populations. In this context, this research focuses on improving the accessibility and use of health information (health literacy) among low-literate populations in Burkina Faso through AI-enabled mobile health solutions. The research methodology includes literature reviews, interviews, surveys and observations to accurately understand the specific needs of low literacy users. Based on this feedback, concrete design principles will be established to guide the development of a prototype Interactive Voice Response (IVR) system in the Dioula language. The mobile service is then evaluated with users to enable iterative improvements to the solution, taking user feedback into account. In addition, this research contributes to the creation of annotated speech data in Dioula to address the lack of speech data for assistive speech technologies for the population. By highlighting the importance of local languages and adapted technologies, this study demonstrates how AI-enabled mobile health solutions can effectively overcome barriers related to literacy to improve the health literacy of marginalised populations. The findings of this study are in line with the United Nations Sustainable Development Goals (SDGs), thus reinforcing their positive impact on the health of vulnerable populations in Burkina Faso.

Keywords:

Mobile Technology, Artificial Intelligence, health literacy, underserved communities.

Unité de recherche

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Résumé étendu

La recherche, la compréhension et l'utilisation adéquate des informations de santé, regroupées sous le terme de "littératie en santé", revêtent une importance cruciale. Ces informations, qu'elles concernent des problématiques de santé, des soins personnels ou la prévention des maladies, contribuent à une meilleure appréhension des risques individuels ainsi que des stratégies de prévention. Par conséquent, elles facilitent la prise de décisions éclairées par les individus en vue d'améliorer leur santé. En outre, ces informations jouent un rôle essentiel en aidant les patients à comprendre leur diagnostic, leur traitement, et à mieux faire face à la maladie. Toutefois, les personnes défavorisées, en particulier celles dont les compétences en lecture et en écriture sont limitées, sont moins enclines à bénéficier des informations disponibles en santé. Ils rencontrent davantage de difficultés en termes de littératie en santé. En Afrique, des initiatives sont mises en œuvre pour améliorer la littératie en santé et réduire les disparités en matière de santé, à travers des interventions, des campagnes de sensibilisation et la promotion de comportements sains.

Heureusement, avec la croissance de la pénétration de la téléphonie mobile en Afrique, une opportunité se présente pour améliorer la littératie en santé des personnes ayant une faible alphabétisation, surtout dans des environnements à ressources limitées où l'accès à l'information en santé demeure un défi de taille. Cette thèse se concentre sur l'étude des solutions de santé mobiles basées sur l'intelligence artificielle pour améliorer la littératie en santé au sein des populations défavorisées, en mettant l'accent sur le contexte spécifique du Burkina Faso. Dans le cadre de cet objectif, les revues de littérature entreprises ont révélé que les solutions mobiles et les jeux sérieux (jeux interactifs à vocation éducative) utilisés dans les zones rurales pour améliorer la littératie en santé, ne prennent pas suffisamment en compte les langues parlées par les populations. De plus, la revue a mis en lumière le déficit de littératie en santé numérique, c'est-à-dire la capacité à utiliser des outils numériques pour trouver, évaluer et comprendre les informations de santé, en particulier en raison de l'accessibilité à internet et des compétences limitées en lecture et en écriture. Ces défis entravent l'utilisation des solutions existantes par les populations peu alphabétisées. Afin de proposer une solution mobile inclusive et de concevoir un prototype visant à faciliter l'accessibilité et l'utilisation des informations de santé pour les personnes peu alphabétisées, différentes approches de conception ont été explorées, notamment la "future literacy", qui se concentre sur l'anticipation et la planification des actions futures selon différents scénarios. Cependant, l'approche de la Conception Centrée sur l'Utilisateur (CCU) en quatre étapes, comprenant la compréhension de l'utilisateur, l'identification de ses besoins, le prototypage et l'évaluation, a été retenue pour cette étude.

La première étape du processus de conception s'est principalement concentrée sur l'acquisition d'une compréhension approfondie des utilisateurs. Pour obtenir ces données, nous avons mené des revues de littérature, des entretiens, des enquêtes et des observations. Cela nous a permis de recueillir des informations détaillées sur les besoins, les valeurs et les attentes des utilisateurs défavorisés et peu alphabétisés vivant au Burkina Faso. Les revues de littérature ont mis en évidence un certain nombre de défis liés à la littératie en santé numérique. Sachant que la compréhension médicale et l'utilisation efficace des informations de santé sont essentielles pour gérer les maladies chroniques en général, nous avons d'abord entrepris une évaluation de la littératie en santé au sein des populations peu alphabétisées, chez les patients diabétiques au Burkina Faso et en Guinée. Nous avons recueilli des données auprès de 97 patients entre 2021 et 2022, répartis entre l'hôpital Sanou Sourou de Bobo Dioulasso au Burkina Faso et l'Hôpital de Donka à Conakry en Guinée, en utilisant deux outils : le Brief Health Literacy pour mesurer la littératie en santé et l'eHEALS pour évaluer la littératie en santé numérique. Il convient de noter que 67% des participants ne savaient ni lire ni écrire.

Les résultats ont révélé que seulement 42,22% des participants en Guinée et 40,4% des participants au Burkina possédaient une littératie en santé suffisante. En ce qui concerne la littératie en santé numérique, seuls 30,11% des répondants en Guinée et 40,2% des répondants au Burkina avaient un niveau adéquat. Ces résultats soulignent l'importance des langues locales dans l'amélioration de la littératie en santé, tout en mettant en lumière la nécessité de renforcer la littératie en santé et la littératie en santé numérique chez les patients diabétiques, en particulier dans les régions où ces compétences sont moins répandues. Les études sur le terrain ont mis en évidence l'utilisation de solutions intégrant les langues locales et des messages vocaux, tels que le service mobile 3-2-1 de Viamo au Burkina Faso, pour améliorer la littératie en santé parmi les populations défavorisées. L'évaluation a été menée auprès de 97 personnes déplacées internes dans le camp de déplacés internes de Pazani au Burkina Faso. Les participants ont été répartis de manière aléatoire en deux groupes: un groupe de contrôle de 49 participants (utilisant le français) et un groupe d'intervention de 48 participants (utilisant la version en langue locale). Une évaluation de la littératie en santé des participants, avant et après l'utilisation du service mobile 3-2-1, a été effectuée. Il est important de noter que 62,2% des participants ne savaient ni lire ni écrire. Après deux semaines d'intervention, le groupe utilisant la version en langue locale (Moré) a connu une augmentation significative de ses connaissances sur le paludisme, passant de 52,6% à 82,93%, tandis que le groupe utilisant la version française a également montré une amélioration, bien que moins marquée, passant de 51,84% à 67,8%.

À la deuxième étape du processus de conception, nous avons établi les spécifications fonctionnelles et non fonctionnelles pour la conception de solutions mobiles inclusives destinées aux populations peu alphabétisées dans le contexte du Burkina Faso. Ces spécifications ont été déterminées à partir d'analyses de la littérature existante et d'études sur le terrain. Parmi les caractéristiques fonctionnelles identifiées, l'intégration d'interfaces vocales, la disponibilité de contenus dans les langues parlées par les utilisateurs (le Dioula) et la priorisation des contenus accessibles sans connectivité Internet ont été jugés essentielle. En ce qui concerne les aspects non fonctionnels, une attention particulière a été accordée à la convivialité, à la sécurité, ainsi qu'à l'intégration de jeux ciblant les populations jeunes.

À la troisième étape du processus de conception, nous avons proposé un prototype de Serveur Vocal Interactif (SVI) basé sur l'IA, fournissant des informations sur la COVID-19 en langue dioula, l'une des langues parlées au Burkina Faso. En nous appuyant sur les informations recueillies lors de la phase de compréhension des utilisateurs et sur les exigences identifiées, nous avons développé un prototype culturellement pertinent et linguistiquement adapté aux populations locales. L'objectif de ce prototype était de démontrer le potentiel de la technologie de l'IA dans la fourniture efficace et inclusive d'informations sur la santé aux populations peu alphabétisées dans le contexte du Burkina Faso. En utilisant la voix comme moyen de communication, nous avons contribué à surmonter les obstacles liés à la littératie en santé, créant ainsi une interface conviviale pour les utilisateurs peu alphabétisés. **La quatrième étape** de notre processus de conception La quatrième étape de notre processus de conception a consisté en un prétest de la solution, comprenant la collecte des commentaires des utilisateurs et l'identification des domaines nécessitant des améliorations. Pour ce faire, nous avons recruté 18 participants peu alphabétisés à Bobo-Dioulasso et utilisé le questionnaire System Usability Scale (SUS), composé de 10 questions, pour évaluer leur niveau de satisfaction vis-à-vis de l'outil. De plus, des tests d'utilisabilité ont été réalisés afin d'évaluer l'expérience des utilisateurs et de recueillir leurs impressions. Des séances de retour d'information ont également été organisées pour obtenir des commentaires plus détaillés sur l'utilisabilité, la pertinence des informations fournies et l'impact perçu sur la compréhension des utilisateurs. Les tests d'utilisabilité et les commentaires, évalués à l'aide de l'échelle de convivialité du système (SUS) auprès de ces 18 participants peu alphabétisés, ont révélé un score moyen de convivialité de 78,75 sur 100. Les utilisateurs ont recommandé de remplacer les commandes du serveur vocal interactif actuellement basées sur des touches numériques par des instructions vocales. Cette adaptation permettrait aux utilisateurs moins alphabétisés de naviguer plus facilement à travers les menus et d'accéder aux informations de santé essentielles sans avoir à maîtriser la numération.

Dans le cadre de l'amélioration du prototype, un aspect clé de cette recherche a été la création d'un ensemble de données vocales annotées en langue dioula. Compte tenu du fait que notre serveur vocal fonctionne à la navigation des touches 1, 2, 3 et 4, nous avons entrepris de transformer ces chiffres en commandes vocales pour faciliter l'utilisation par des utilisateurs peu alphabétisés. La collecte et l'annotation de ces données linguistiques ont nécessité une collaboration étroite avec la communauté locale. Nous avons travaillé en étroite collaboration avec des locuteurs natifs de la langue dioula pour enregistrer des échantillons vocaux et transcrire ces enregistrements, créant ainsi un corpus de données linguistiques. Avec environ 1 400

enregistrements audio, nous les avons ensuite entraînés en appliquant des techniques d'augmentation de données. Les résultats de cette étude ont révélé une amélioration de la précision du modèle, passant de 51% à 96%. De plus, les matrices de confusion ont démontré la capacité accrue du modèle à prédire avec justesse, avec une reconnaissance correcte de 1 762 occurrences sur 1 817 du chiffre "1" après l'augmentation des données. En outre, l'étude a mis en lumière une réduction significative de la perte, passant de 205% à 14% après la mise en œuvre de l'augmentation des données. Ces conclusions soulignent l'importance cruciale de l'augmentation des données dans l'amélioration des performances du modèle et la résolution des problèmes de surajustement, mettant en évidence le potentiel de cette technique pour pallier la rareté des données dans les contextes à ressources limitées. L'intégration de ce modèle entraîné sur les chiffres 1, 2, 3 et 4 au serveur vocal interactif permettra aux utilisateurs moins alphabétisés de naviguer plus facilement à travers les menus par la voix dans la langue locale dioula, et d'accéder aux informations de santé essentielles sans avoir à maîtriser la numération.

Les travaux de recherche ont identifié les spécifications techniques essentielles pour le développement de solutions de santé mobile adaptées aux utilisateurs peu alphabétisés au Burkina Faso. Les recommandations soulignent des principes tels que l'accessibilité, la convivialité et la pertinence culturelle pour mieux répondre aux besoins des utilisateurs défavorisés. De plus, ces travaux ont démontré la contribution significative des langues locales et des interfaces vocales dans l'amélioration de la littératie en santé au sein des populations vulnérables. La création d'un ensemble de données linguistiques annotées en langue dioula dans le cadre de l'initiative Mozilla Common Voice, ainsi que le déploiement du modèle de reconnaissance des chiffres 1, 2, 3 et 4 en dioula, ouvrent de nouvelles perspectives pour faciliter l'accessibilité des informations de santé à travers les technologies mobiles, renforçant ainsi la littératie en santé au sein des communautés défavorisées. La contribution de ces travaux est en ligne avec les objectifs de développement durable en favorisant un accès équitable aux soins de santé et en soutenant l'amélioration de la santé des populations défavorisées.

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List of terms and abbreviations

AI	Artificial Intelligence
ASR	Automatic Speech Recognition
BHLS	Brief Health Literacy Screen
CDC	Centres for Disease Control and Prevention
DTMF	Dual Tone Multi-Frequency
eHealth Literacy	electronic Health literacy
eHEALS	eHealth Literacy Scale
FL	Futures Literacy
FLL	Futures Literacy Laboratories
GUI	Graphic User Interface
GSM	Global System for Mobile Communications
HL	Health Literacy
HLQ	Health Literacy Questionnaire
IDP	Internally displaced people
IVR	Interactive Voice Response
KAP	Knowledge, Attitudes and Practises
mHealth	mobile Health
NGO	Non-Governmental Organisation
NLP	Natural Language Processing
LRL	low-resource language
SDG	Sustainable Development Goals
SSA	Sub-Saharan Africa
SUS	Usability Scale Questionnaire
UCD	User-Centered Design
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
UTAUT	Unified Theory of Acceptance and Use of Technology
WHO	World Health Organization
PLP	Perceptual Linear Prediction
LPC	Linear Prediction Coding
MFCC	Mel-Frequency Cepstrum Coefficients
FFT	Fast Fourier Transform

General introduction

1 Background and Motivation

Health literacy plays a crucial role in understanding and using health information effectively. It enables individuals to make informed decisions about their health, take preventive measures and manage health conditions effectively. In sub-Saharan Africa (SSA), however, some challenges further emphasise the importance of health literacy. SSA countries face numerous health challenges, including limited access to quality health services, high disease burden and health inequalities [Koumamba, 2021]. Many communities in the region lack adequate health infrastructure, such as health facilities and health professionals, making it difficult for people to access timely diagnosis, appropriate treatment, and preventive measures. In addition, SSA is heavily burdened by infectious diseases such as malaria, HIV/AIDS and tuberculosis, which require targeted prevention and management strategies based on people's level of health literacy. Low health literacy is a major problem in SSA, often influenced by limited education, language barriers and cultural beliefs. Many people have difficulty understanding health information, navigating the health system, and making informed decisions about their health. This lack of health literacy hinders disease prevention and contributes to poor health outcomes [Ouedraogo, 2022b]. Furthermore, linguistic, cultural diversity, and oral traditions in SSA pose additional challenges.. There are a variety of languages and different cultural practices in the region. Effective communication of health information requires overcoming language barriers and adapting interventions to the local cultural context. Providing health information in local languages and taking cultural beliefs and practices into account is crucial to ensure that information is accessible and culturally appropriate.

Despite these challenges, It's important to highlight that in 2021, over half (53%) of the adults residing in rural areas of LMICs (Low and Middle-Income Countries) were utilizing mobile internet services [Anne, 2022]. This presents an opportunity to use mobile technologies, including AI-enabled solutions, to address gaps in health literacy and improve access to relevant health information. AI-powered mobile health solutions can deliver personalised, culturally appropriate, and accessible health information through language-based interactions, local language support and user-friendly interfaces [Pandey, 2022]. Addressing health literacy challenges in SSA is in line with the global Sustainable Development Goals SDG, in particular SDG 3 (health and well-being) and SDG 10 (reduce inequalities). By improving health literacy, research should help reduce health inequalities, improve access to healthcare and empower people to make informed decisions about their health [England, 2015]. In summary, in the general context, the background and motivation underline the importance of health literacy for effective health decision-making. In the specific context of SSA, the region faces challenges of limited access to quality healthcare, high disease burden, low health literacy, linguistic and cultural diversity, and the potential of mobile technology and AI-enabled solutions. By addressing these challenges, the current research aims to contribute increasing health literacy, improving access to healthcare and ultimately contributing to better health outcomes in SSA.

2 Overview of health literacy and its importance in health decision-making

Health literacy refers to an individual's ability to access, understand and use health information to make informed decisions about their health [Buchbinder, 2011]. It is an important skill that enables individuals to navigate the health system, understand health concepts and engage in health-promoting behaviours. In the context of SSA, health literacy promotion is particularly important as underserved and poorly educated populations face challenges. These populations often lack access to quality health services, have limited educational opportunities, and face language and cultural barriers. As a result, it can be difficult for them to understand health information, make informed decisions and manage their health effectively. Low health literacy in SSA can contribute to poor health outcomes, delayed or inappropriate use of health services and inadequate uptake of preventive services [Amoah, 2018]. This exacerbates health inequalities and perpetuates inequities in access to health care and health information.

It is therefore crucial to develop interventions and strategies that specifically target these underserved populations and address their health literacy needs. Efforts to improve health literacy in SSA must consider the linguistic and cultural diversity of the region. Local languages and culturally appropriate health information are essential to ensure effective communication and understanding among literate populations. When health information is tailored to local languages people are more likely to understand and act on the information, leading to better decision-making and outcomes.

The increasing prevalence of mobile devices in SSA provides a unique opportunity to leverage technology, including AI-powered mobile health solutions, to improve health literacy. Mobile health solutions can deliver personalised and accessible health information through voice-based interactions and user-friendly interfaces [Siau, 2006]. They can bridge the literacy gap and reach underserved populations who may have limited literacy skills but access to mobile phones. By focusing on underserved populations with low literacy skills in SSA, interventions can help people take control of their health and well-being. By improving health literacy, people are better able to prevent and manage disease, make decisions together with health care providers, and adopt healthier behaviours. Ultimately, improving health literacy in SSA helps to reduce health inequalities, improve health outcomes, and promote equitable access to healthcare for all people in the region.

3 Challenges Faced by underserved communities with limited health literacy

Addressing the many challenges faced by underserved communities with limited health literacy requires a comprehensive and multi-faceted approach. One of the biggest challenges is limited access to reliable and relevant health information. This lack of access is often due to factors such as limited access to health facilities, libraries or internet connections, which limit people's ability to obtain accurate and up-to-date health information, making it difficult to make informed decisions about their health. In addition, language and cultural barriers are also major obstacles. These communities may not have access to health information in their native language or in culturally appropriate formats, leading to misunderstanding and potential mismanagement of health conditions. Despite traditional medical practitioners mainly relying on oral prescriptions and consultations in local languages, which could enhance accessibility for those with low literacy, they are still challenged by the necessity of writing prescriptions rather than solely providing them verbally, adding another layer of difficulty [Mokgobi, 2013].

In addition, limited educational opportunities exacerbate health literacy issues. A significant proportion of underserved populations have low levels of education, making it difficult for them to read, understand and correctly interpret health information. This lack can lead to confusion, misinterpretation and suboptimal health decisions. In addition, the complexity of the health system compounds these challenges. Understanding health insurance, navigating medical appointments and deciphering medical terminology can be overwhelming, often resulting in missed appointments and missed treatment plans. Stigma and discrimination are also significant barriers, as marginalised populations may face these issues in the health system that prevent them from seeking treatment, disclosing health problems or actively participating in health decision-making. These barriers further limit access to and use of health information and exacerbate health inequalities. Numeracy also plays a crucial role in health literacy. Appropriate understanding and interpretation of numerical information such as dosage instructions, laboratory results and health measurements are critical for effective health decision-making. Limited numeracy skills in underserved populations can lead to medication errors, misunderstanding of risk factors and difficulties in managing chronic diseases.

Furthermore, the increasing reliance on technology as a source of health information poses a challenge for people with limited digital literacy. Insufficient familiarity with digital devices, internet use and online resources makes it difficult for them to access and evaluate digital health information, limiting their ability to benefit from available resources. To address these multiple challenges, efforts must focus on increasing access to reliable health information, providing culturally and linguistically appropriate resources, improving educational opportunities, facilitating health information and promoting an inclusive and non-discriminatory health environment. With this holistic approach, it becomes possible to work towards bridging the health literacy gap and empowering underserved communities to make informed decisions about their health and overall well-being.

4 Research Questions and Research Objectives

In this study, we aim to explore the transformative potential of mobile technologies in improving health literacy among people with low education in resource-poor settings, with Burkina Faso as our primary focus. To guide our comprehensive investigation, we have formulated several key research questions that will guide our research efforts.

Our first research question addresses an in-depth investigation of the impact of local language-based mobile technology, specifically the use of voice assistance technology, on promoting health literacy among people with limited literacy skills in Burkina Faso.

Research question 1. How effective is the use of local voice-based mobile technology, particularly assistive speech technology, in improving the health literacy of people with limited literacy skills in Burkina Faso? We aim to determine the effectiveness of this approach by providing key health information and interventions in the local language through voice-enabled solutions. This research aims to shed light on the enormous potential of local language-based technologies to improve health understanding and facilitate informed decision-making in resource-poor settings.

With our second research question, we turn to the area of mobile technologies used in health literacy interventions in low-resource settings and seek to identify the critical features and characteristics of these technologies.

Research question 2. What are the critical features and characteristics of mobile technologies used in health literacy interventions in resource-poor settings in Burkina Faso? We aim to identify the distinctive

characteristics of these technologies and decipher the complex factors that influence their adoption and use by people with limited literacy skills. This comprehensive research covers a wide range of aspects, including accessibility, usability, affordability and cultural acceptance of these technologies. Our ultimate goal is to gain valuable insights into the challenges faced by the target group, which will in turn inform the development of interventions that are not only accessible but also inherently user-friendly.

Our third research question concerns the design and development of a mobile-based technology solution that is carefully tailored to strengthen the health literacy of the low-education population in Burkina Faso.

Research question 3. How to design and develop a contextually relevant mobile radio-based technology solution that promotes health literacy among people with low literacy levels in Burkina Faso? We embark on a journey to explore the methodology required to develop a contextually relevant solution that takes into account the linguistic, cultural and educational aspects of the target group. Our approach is firmly rooted in user-centred principles and carefully considers user preferences and requirements to ensure that the resulting technology is not only effective but also intuitive and user-friendly.

Finally, our fourth research question addresses the complex area of data creation and focuses on the creation of a language dataset in the Dioula language.

Research Question 4. How to create a comprehensive and reliable language dataset such as Dioula language? Creating a speech dataset aims to overcome the inherent limitations associated with annotated datasets for language-based AI solutions in local languages on the African continent. Our research looks in depth at the methodology and approach required to carefully construct a comprehensive and reliable language dataset in the Dioula language. We conscientiously explore a variety of data collection, transcription and annotation strategies that culminate in the creation of a robust and representative dataset tailored to the specific needs of AI solutions in speech technology.

Our overall goal is to overcome the limitations of annotated datasets, especially in the context of local languages in Africa, and thus make an important contribution to the advancement of AI solutions in the field of language technology. We are trying to figure out how the availability of a well-structured speech dataset in the Dioula language can be a transformative force that greatly improves the performance and accuracy of speech recognition, Natural Language Processing (NLP) and various other language-related applications. Through our rigorous exploration of these carefully formulated research questions, this study strives to provide a holistic and nuanced understanding of the pivotal role that mobile technology plays in strengthening health literacy in resource-poor regions of Burkina Faso.

5 Contributions of the Thesis

This thesis presents four contributions aiming at contributing to reducing inequalities in health literacy in resource-poor settings, with a particular focus on Burkina Faso.

Contribution 1. The formulation of the paper "Guidelines for Inclusive Mobile Health" presents actionable strategies for the development of mobile health solutions that are accessible to all. By emphasising the integration of local languages and user-friendly interfaces, the paper seeks to improve engagement and accessibility in diverse communities. In addition, the guidelines emphasise the importance of ensuring technical compatibility and addressing non-functional aspects such as usability, security and reliability to effectively disseminate health information in underserved communities.

Contribution 2. The study "Impact of Mobile-Based Local Language and Voice Technology" highlights the tangible benefits of voice-driven technologies in improving the health literacy of marginalised populations. By presenting concrete evidence of the transformative capabilities of these technologies, the study emphasises the central role of local languages and voice-driven mobile technologies in addressing challenges related to limited literacy, particularly in Burkina Faso. The study argues for the strategic use of local languages and voice-activated technologies to improve health outcomes and overall well-being in underserved regions such as Burkina Faso.

Contribution 3. A major milestone is the development of an AI-driven interactive voice response (IVR) prototype, customised to provide health information in the Dioula language. This ground-breaking prototype is a testament to the potential of AI in improving health literacy, especially for people with limited reading skills. By focusing on user-centred design and indigenous language integration, this initiative contributes to meaningful interventions that drive positive change and empowerment for underserved populations.

Contribution 4. The creation of a specialised language dataset for the Dioula language that can be likened to an important navigational tool that enables computers to understand and communicate effectively in the Dioula language. This substantial contribution represents a significant step in the use of technology to improve access to health information for Dioula speakers. This dataset reflects a firm commitment to promoting linguistic inclusion and better understanding, and catalyses improving technological accessibility and connectivity in communities that face various barriers.

Taken together, the dissertation presents practical strategies for inclusive mobile health solutions, emphasising the integration of local languages and user-friendly interfaces to improve accessibility in diverse communities. It highlights the transformative impact of voice-activated technologies in improving the health literacy of underserved populations and advocates for the use of local languages and voice-activated mobile technologies to improve health outcomes. The development of an AI-powered interactive voice response prototype and a specialised language dataset for the Dioula language are important milestones that highlight the potential of technology in promoting language inclusion and better understanding in underserved communities.

6 Thesis Roadmap

The dissertation consists of two parts, each of which makes its own contribution to the discourse. The first part, which covers chapters 1 to 3, provides a comprehensive examination of the existing landscape.

Part I: Current state of the art

- **Chapter 1** critically analyses the indispensable role of health literacy in underserved communities, traversing theoretical frameworks such as social cognition theory and cultural competence theory. Examination of conceptual frameworks such as the Health Literacy Framework and the Empowerment Framework strategically address existing health literacy disparities.
- **Chapter 2** shifts the focus to health literacy interventions in SSA, linking these initiatives closely to the [SDG](#). Cooperation with renowned organisations such as UNESCO and the Africa CDC is examined in order to illustrate the connection between health literacy, education and individual self-determination. In parallel,
- **Chapter 3** ventures into the area of guidelines for the development of inclusive mobile solutions, focusing on key principles such as the inclusion of diverse interaction opportunities and ensuring cultural sensitivity.

The following Part II spanning chapters 4 to 7, is dedicated to explaining the main contributions of this thesis:

- **Chapter 4** provides an insightful assessment of the transformative impact of mobile speech and language technology on health literacy, particularly in Burkina Faso and Guinea. The focus is on technology-enabled interventions, with particular emphasis on the need for user-centred design.
- **Chapter 5** scrutinises the usability of an AI-driven interactive voice response (IVR) system in Burkina Faso. This section shows the immense potential of such technologies in improving health literacy, especially among lower-educated populations.
- **Chapter 6** looks at the challenge of developing a voice-enabled mobile interface for Dioula speakers in West Africa and explains the importance of specialised language models and the transformative role that speech recognition technology plays in expanding access to essential services.
- **Chapter 7** concludes the journey and addresses the implications and recommendations arising from the multi-faceted exploration of essential functions, language and location-based technologies and the development of an AI-driven prototype in Burkina Faso. This chapter emphasises the critical considerations required for the development of effective health interventions, with a particular focus on accessibility, cultural relevance and inclusivity.

PART I: STATE OF ART

Chapter 1

Health Literacy and its Importance in Underserved Communities

1 Introduction

Health literacy is a critical component in understanding and navigating the complex landscape of health-care. It enables individuals to make informed health decisions, ultimately leading to improved health outcomes. However, certain populations, especially those who are underserved and vulnerable, face significant challenges in achieving adequate health literacy due to factors such as limited access to healthcare services, socio-economic disparities, cultural differences, and educational barriers [Berkman, 2011b] [Kindig, 2004]. The concept of health literacy extends beyond the mere ability to read and comprehend health information. It includes a broader set of skills such as critical thinking, effective communication, and empowerment, which allow individuals to become active advocates for their healthcare needs [Berkman, 2011b]. In communities where access to healthcare is scarce, promoting health literacy becomes even more crucial. This chapter highlights the significance of health literacy in underserved communities, shedding light on the specific challenges they face and the consequences of limited health literacy on their health outcomes. By understanding the specific factors contributing to low health literacy in underserved communities, tailored interventions and strategies can be developed to improve health literacy and promote health equity [Kindig, 2004]. The chapter explores the socio-economic, cultural, and educational factors that influence health literacy in underserved populations. It discusses the implications of limited health literacy, including disparities in healthcare utilization, increased healthcare costs, and poorer health outcomes. Furthermore, it emphasizes the role of health literacy as an empowering tool for individuals in underserved communities, enabling them to take an active role in their healthcare decision-making. Understanding the unique challenges and implications of health literacy in underserved communities lays the groundwork for subsequent chapters in Part I, which will examine existing efforts and interventions aimed at improving health literacy within these populations. Through research, analysis, and the sharing of best practices, the goal is to bridge the gap in healthcare and ensure equitable access to quality healthcare for all.

2 Concept definitions, measurements and Impact of Health Literacy

2.1 Literacy and Digital literacy

UNESCO¹ defines literacy as more than a simple ability to read, write and count. It sees it as a continuum of learning that includes digital skills, media literacy and other job-specific skills. Literacy is an essential component of empowerment and leads to higher labour force participation, better health outcomes and sustainable development. UNESCO¹ actively promotes literacy through its global network, focusing on disadvantaged groups, digital literacy and literacy monitoring. In addition, UNESCO¹ places great emphasis on digital literacy as it is essential for secure access to, management and creation of information in today's digitalised world. Digital literacy is crucial for fostering critical thinking and resilience in the face of misinformation and online risks, especially among young people.

Low literate in this work refers to young people or adults who have limited skills to read or write.

Illiterate refers to young people or adults who cannot read and write.

2.2 Health literacy

Health literacy (HL) is a relatively recent concept within health promotion that encompasses various outcomes related to health education and communication efforts [Nutbeam, 2000b]. Emerging in the 1970s [Simonds, 1974], its importance has steadily increased in both public health and healthcare domains, gaining attention on the European health agenda and expanding internationally to include public health contexts [European Commission, 2007] [Kickbusc, 2008] [Pleasant, 2008] [World Health Organization, 2009] [Kickbusch, 2013]. HL is crucial in navigating the complex demands of health in modern society. Low health literacy has been significantly associated with adverse health outcomes, emphasizing the global importance of promoting HL [DeWalt, 2004; Sudore, 2006; Baur, 2010; Kamarage, 2003]. Consequently, various national and international organizations have prioritized health literacy as a key area for research [Agency for Healthcare Research and Quality, 2008; World Health Organization, 2009]. Despite growing attention to HL by European health policymakers, researchers, and practitioners, information about its status globally and in Europe remains limited [Sørensen, 2015]. This scarcity is even more pronounced in developing countries, where research on HL is scarce, despite the critical role of health information, a key component of health literacy. However, the significance and relevance of health literacy have not gone unnoticed by stakeholders in developing regions, where resources for investigating health literacy are limited. Furthermore, extensive research has revealed the detrimental effects of low health literacy on various health aspects, underscoring the need for comprehensive approaches to health literacy [Berkman, 2011a]. Initially focused on individual skill deficits and the provision of factual health information, the understanding of health literacy has evolved to encompass multiple dimensions, recognizing its dynamic nature and the interplay between individual skills and healthcare systems [Berkman, 2011a]. Moreover, the 1992 National Adult Literacy Survey in the United States highlighted challenges faced by American adults in using health-related information [Kutner, 2006]. Overall, the concept of health literacy plays a critical role in shaping health behaviours and outcomes, emphasizing the need for concerted efforts to address challenges and promote equitable access to quality healthcare. HL has attracted a great deal of attention in the field of public health, with numerous definitions highlighting its crucial role in empowering individuals to access, understand and use health information effectively. WHO defines it as the cognitive and social skills that determine a person's motivation and ability to use information to promote health [Nutbeam, 2000a].

1. <https://www.unesco.org/en/literacy/need-know>

The American Medical Association (AMA) emphasises the confluence of skills needed to function in health care [Bresolin, 1999]. Nutbeam emphasises the personal, cognitive and social skills that are essential for promoting and maintaining good health [Nutbeam, 2000a]. The Institute Of Medicine (IOM), meanwhile, emphasises the role that individuals have in making appropriate health decisions [Nutbeam, 2000a]. Kickbusch and Maag describe it as a tool for individuals to take control of their health and take responsibility for their well-being in different contexts [Kickbusch, 2013]. Zarcadoolas et al. emphasise the range of competencies associated with informed health management decisions [Zarcadoolas, 2003; Zarcadoolas, 2006].

Numerous studies have examined health literacy as a multi-level construct, involving different social and cognitive skills. Nutbeam initially proposed a three-level model [Nutbeam, 2000b]: **functional health literacy**, **interactive health literacy**, and **critical health literacy**. This model has been further refined and expanded by various researchers. For example, Schillinger interpreted functional health literacy as encompassing literacy and numeracy [Schillinger, 2001], while Chinn considered critical health literacy as understanding social determinants of health and engaging in collective actions [Chinn, 2011]. Sykes et al proposed that critical health literacy encompasses advanced personal skills, health knowledge, information skills, effective interactions between service providers and users, informed decision-making, and empowerment, including political actions [Sykes, 2013]. Manganello added media literacy as a separate component in health literacy for adolescents, emphasizing the importance of critically assessing media messages [Manganello, 2008]. Liao et al examined the Nutbeam model in children, defining functional health literacy as understanding basic health concepts, comprehending the relationship between health behaviors and outcomes, and performing basic health behaviors; interactive health literacy as maintaining good relationships with peers, appropriately expressing oneself and responding to others, and understanding various information from the environment [Liao, 2017]. These different perspectives contribute to a comprehensive understanding of health literacy as a complex and multifaceted concept.

The concept is further elaborated by several other scholars, including Paasche-Orlow and Wolf [Zarcadoolas, 2006], the EU [European Commission, 2007], Pavlekovic, Rootman and Gordon-Elbihbety, Ishikawa and Yano [Pavlekovic, 2008], Mancuso [Mancuso, 2008], the Australian Bureau of Statistics [Australian Bureau of Statistics, 2008] and Yost et al. [Yost, 2009], all of whom emphasise the critical role of health literacy in promoting informed decision-making and better health outcomes.

2.3 Health literacy recent evolution

In its 2022 report on the development of health literacy for the prevention and control of non-communicable diseases [Organization, 2022], the WHO provides a comprehensive definition of health literacy and outlines its multifaceted nature. Developing health literacy involves collaborative efforts by health workers, services, systems, organisations and policy makers in all sectors of government to improve the knowledge, confidence and comfort of individuals, families, groups and communities. This is achieved by creating an enabling environment that facilitates access, understanding, evaluation, recall and use of health information and services through various communication channels and social resources. Community health literacy encompasses knowledge, trust in information, health-promoting habits and relationships with external sources of information within the community, with family, peer and community interactions playing a central role. At the individual level, health literacy encompasses an individual's accumulated knowledge, confidence and security in dealing with health information that is shaped by daily activities and social interactions across generations. Health literacy refers to the ability of health care institutions to recognise and accommodate diverse traditions, strengths, needs and preferences related to health literacy, thus creating an environment

that ensures equitable access to health information and services and promotes the health and well-being of individuals, families, groups and communities.

2.4 Health literacy measurements tools

Over the years, health literacy measurement tools have been developed to assess people's abilities to understand and use health information effectively. These tools have been summarized in Table 1.1 below, including the Rapid Estimate of Adult Literacy in Medicine (REALM)[Davis, 1992]., introduced in 1991. REALM assesses a person's ability to read medical terms and words. The Test of Functional Health Literacy in Adults (TOFHLA) [Parker, 1995], introduced in 1995, assesses both reading comprehension and numeracy skills related to health. In 2004, the Health Literacy Assessment Tool (HLAT-8) [Abel, 2015] was developed. It consists of eight items that assess respondents' self-reported difficulty in various health-related tasks. The Newest Vital Sign (NVS)[Weiss, 2005], introduced in 2005, is a short screening tool that measures health literacy and numeracy. It assesses a person's ability to interpret a food label and answer related questions. The Single Item Literacy Screener (SILS) [Morris, 2006], developed in 2006, is a simple screening question that asks people to rate their reading ability on a scale. It provides a quick assessment of functional literacy skills. The Health Literacy Questionnaire HLQ by Richard Osborne et al [Osborne, 2013], is a comprehensive instrument that assesses several dimensions of health literacy, including understanding health information, navigating the health system and social support. In addition to these instruments, the Communicative and Critical Health Literacy Scale (CCHL) [Ishikawa, 2008] was also introduced in 2013. The Brief Health Literacy Screen (BHLS) is a succinct three-question tool utilized in clinical settings to efficiently assess patients' health literacy levels and address their specific communication needs. These measurement tools have provided valuable insights into the level of health literacy of individuals and have been of great importance for research and health practice. They contribute to a better understanding of health literacy and help identify areas where targeted interventions can be taken to improve health outcomes.

Table 1.1 – Health literacy measurements tools

measurement tools	Authors	Descriptions
Rapid Estimate of Adult Literacy in Medicine(REALM)	(Davis,Crouch, Long,Jackson, 1991)[Davis, 1992].	measures word recognition and pronunciation skills for medical terms and words
Health Literacy Assessment Tool (HLAT-8).	(Abel, Hofmann, Ackermann, Bucher, Sakarya, 2015)[Abel, 2015]	Consists of eight items assessing self-reported difficulty in healthrelated tasks.
Newest Vital Sign (NVS)	(Weiss, Mays, Martz, Castro, DeWalt, 2005)[Weiss, 2005].	A brief screening tool that measures health literacy and numeracy skills using a foolabel
Single Item Literacy Screener (SILS)	(Morris, MacLean, Chew, Littenberg, 2006)[Morris, 2006].	A simple screening question that assesses self-rated reading ability
Health Literacy Questionnaire (HLQ)	(Osborne, Batterham, Elsworth, Hawkins, Buchbinder, 2013) [Osborne, 2013].	A comprehensive tool assessing various dimensions of health literacy
Communicative and Critical Health Literacy Scale (CCHL)	(Ishikawa, Takeuchi,Yano, 2008)[Ishikawa, 2008].	Assesses the functional, communicative, and critical health literacy levels

2.5 Impact of health literacy

The correlation between health literacy and different health outcomes for different diseases has attracted considerable attention in recent studies [Berkman, 2004; DeWalt, 2004]. In particular, research has highlighted the impact on self-reported poor health, increased risk of hospitalisation, lower attendance at cancer screening and impaired self-management in patients with diabetes [Baker, 1998; Baker, 1997; Garbers, 2004;

Kim, 2004]. In addition, the impact of health literacy extends to haemoglobin A1C levels in diabetics and has been associated with higher health care utilisation and higher health care costs in Medicare-insured individuals [Schillinger, 2002; Howard, 2005]. For older people, the impact is even more profound, as low health literacy is associated with a greater burden of chronic disease, impaired physical function and poorer mental health [Rudd, 2004; Wolf, 2005; Kim, 2010]. In addition, low health literacy has been identified as a potential risk factor for increased mortality [Sudore, 2006]. It is critical to understand the underlying mechanisms that contribute to the relationship between health literacy and health outcomes. Several factors, including race, ethnicity, education and health-related behaviours, have been proposed to explain this association [Cutler, 2006]. Studies have shown that race and ethnicity are associated with both low health literacy and poorer health outcomes and that accounting for literacy attenuates the impact of ethnic status on health outcomes, highlighting its role in health inequalities [Curtis, 2012]. Income and educational attainment have also been associated with health, possibly through differences in health maintenance and prevention or better access to health care through health insurance. In addition, higher levels of education or income may lead to less economic hardship and stressors, contributing to better health outcomes [Ross, 1999]. A comprehensive assessment that incorporates these factors is essential for a nuanced understanding of the complex relationship between health literacy and health outcomes.

3 Frameworks of health literacy

Health literacy frameworks play a pivotal role in providing structured approaches to understanding and addressing the intricate concept of health literacy. These frameworks encompass both theoretical and conceptual dimensions, offering a comprehensive perspective on how health literacy operates across diverse populations and contexts.

3.1 Definition of theoretical and conceptual framework

Theoretical frameworks on health literacy, which include social cognitive theory, health behaviour theory, cultural competence theory, and social determinants of health theory, offer explanations and insights into the factors that influence health literacy and its outcomes [Bandura, 1986; Glanz, 2008; Solar, 2010]. These frameworks help to understand how behaviours are acquired, how different factors affect health-related decisions, the importance of cultural diversity, and the role of social determinants in shaping health outcomes. On the other hand, conceptual frameworks such as the Health Literacy Framework, the Ecological Model of Health Literacy, the Cultural Health Capital Framework, the Teach-Back Method Framework and the Empowerment Framework provide visual or mental maps of the key concepts, relationships and dimensions that constitute health literacy [Howard, 2006; Schillinger, 2002; Wallerstein, 2006; Sørensen, 2012]. These frameworks help researchers to categorise and analyse the different facets of health literacy by dividing them into functional, interactive and critical health literacy, thus providing a structured approach to addressing health literacy challenges. In the context of underserved communities in Africa, several key theoretical and conceptual frameworks are relevant to understanding and addressing health literacy challenges.

3.2 Theoretical and conceptual frameworks: the context of underserved communities in Africa

A number of important theoretical and conceptual frameworks come into play. These frameworks offer valuable insights into understanding and addressing the challenges of health literacy. Here we look at some

prominent health literacy frameworks that are particularly relevant and commonly used in the context of underserved communities:

3.2.1 Theoretical frameworks in underserved communities

Theoretical frameworks, such as Albert Bandura's social cognitive theory [Bandura, 1986], are relevant in underserved African communities where traditional practices and community interactions significantly influence health-related behaviours. This theory helps to understand and to address inequalities in health literacy. It explains how individuals learn health behaviours by observing respected members of the community who serve as role models [Bandura, 1986]. Health behaviour theory, including the work of Rosenstock, Ajzen, Prochaska and DiClemente [Glanz, 2008], takes an in-depth look at the various factors that influence health-related decisions and actions. By identifying and addressing barriers to improving health literacy and adapting interventions to the unique cultural and contextual characteristics of underserved communities, this theory plays a critical role in regions with limited access to health care [Glanz, 2008]. In the context of underserved African communities, Josepha Campinha-Bacote's [Campinha-Bacote, 1999] theory of cultural competence is of utmost importance. It emphasises the need to understand and respect the diverse cultural landscape in health care. This theory facilitates the delivery of culturally sensitive care and ensures that healthcare providers align their services with the cultural values and beliefs of the populations they serve [Campinha-Bacote, 1999]. The social determinants of health theory, developed by Michael Marmot, highlights the profound influence of social, economic and environmental factors on health outcomes. In regions characterised by marked socioeconomic inequalities, this theory offers crucial insights into the deeper causes of health literacy challenges. By addressing the larger social inequalities, this framework advocates for the improvement of health literacy and thus for the improvement of overall health outcomes [Solar, 2010].

3.2.2 Conceptual frameworks in underserved communities

The Health Literacy Framework, characterised by its focus on functional, interactive and critical components, provides a structured approach to strengthening health literacy by identifying specific areas of deficiency [Nutbeam, 2000a]. In underserved African communities, this framework helps identify gaps in functional health literacy, such as understanding medication instructions, and tailor interventions to address these gaps. In parallel, the ecological model of health literacy, which incorporates the broader context of an individual's life, helps to understand community dynamics and the impact of limited resources on health-related decisions. Particularly in underserved regions, this model illustrates how community dynamics and limited resources affect health literacy and guides interventions that take these factors into account [Sørensen, 2012]. The Cultural Health Capital Framework emphasises the influence of cultural knowledge and resources on health behaviours and guides initiatives to disseminate health information in a culturally sensitive manner. In underserved communities, this framework provides strategies for using cultural beliefs and practices to improve health literacy [Kreps, 2006]. In addition, the Teach-Back Framework serves as a practical method for assessing understanding and improving communication to ensure that health information is understood, retained and accurately communicated. In regions where effective communication bridges the health literacy gap, this method helps health care providers confirm patients' understanding of health information and improve health literacy [Nutbeam, 2000b]. Finally, the Empowerment Framework emphasises empowering individuals to actively manage their health and promotes collaborative and participatory approaches to improving health literacy. This aspect is particularly important in underserved African areas, where the Empowerment Framework advocates for community engagement and active participation in health decision-making [Agyemang, 2022]. By seamlessly integrating these established theoretical and conceptual

frameworks, health professionals and policymakers can take a comprehensive approach to addressing health literacy challenges in underserved communities, promoting better health outcomes and equitable access to quality care.

4 Current status of health literacy in Sub-Saharan Africa

The state of health literacy in SSA remains a pressing issue, underscoring the necessity for accessible and reliable health information to facilitate informed decision-making for both individuals and communities. The US Agency for Healthcare Quality and Research (AHQR) has emphasized the dearth of comprehensive assessments of health literacy and its impacts, particularly in developing nations [Berkman, 2011a]. A comprehensive multinational study conducted across 14 countries in SSA revealed a 35.77% prevalence of health literacy, with significant variations observed across countries, ranging from 8.51% in Niger to 63.89% in Namibia [McClintock, 2020]. Furthermore, the study highlighted slightly lower health literacy rates among women at 34.08% compared to 39.17% among men, and underscored the significant influence of educational attainment on health literacy levels, with only 8.93% of individuals with primary education or less demonstrating adequate health literacy [McClintock, 2020]. Given the increasing digitalization in the region, leveraging e-health solutions, facilitated by the high mobile penetration rate of 95%, is crucial for addressing the challenges associated with rural health literacy.

5 Factors contributing to limited Health Literacy

Health literacy, a critical factor influencing health outcomes [Keller, 2008], is shaped by several elements, including individual characteristics, social and environmental contexts, and dynamics within health systems [Abdullah, 2020a]. Presented in Figure 1.1, these factors collectively affect the accessibility and understanding of health-related information, highlighting the importance of understanding and addressing them to improve health literacy and overall well-being.

5.1 Individual-Level Factors

Educational attainment is a critical factor at the individual level that has a significant impact on the ability to understand complex health information and medical instructions, especially among people with lower levels of education. To counteract this, health professionals can use simple language and visual aids to facilitate understanding. Language skills also play a crucial role in individual health literacy, with limited understanding of the language used in health communication being a barrier. Health organisations can overcome this by using interpreters, providing multilingual health materials and ensuring culturally sensitive communication. Cognitive abilities also have an impact on health literacy, especially for people with cognitive impairments or learning difficulties who may have difficulty processing and retaining health information. In such cases, simplified language, repetition and visual aids can facilitate understanding. Pre-existing health knowledge also has a significant impact on a person's health literacy. Insufficient familiarity with health-related concepts and information can limit health literacy. Initiatives such as introducing health education in schools and community programmes from an early age can build a solid foundation of health knowledge and promote informed decision-making. Age is another influential factor that particularly affects the health literacy of older adults, who have difficulty keeping up with the rapid development of health technologies and terminology. Adapting health information to the specific needs of older people, using senior-friendly communication methods and providing the necessary technical support can mitigate these challenges. In

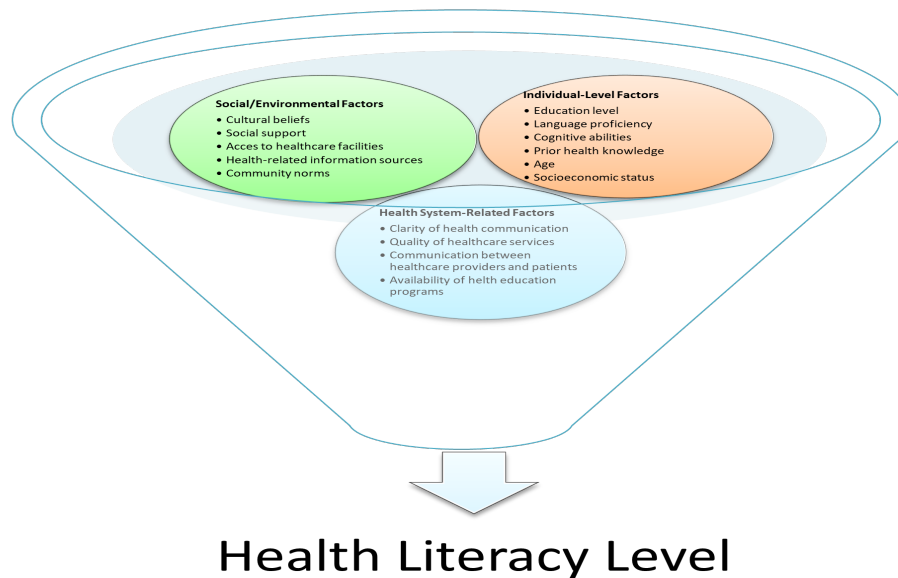


Figure 1.1 – Factors contributing to limited Health Literacy

In addition, socio-economic status (SES) plays an important role, often resulting in people of lower social status having limited access to health resources and information. To mitigate this inequality, health organisations can implement public programmes that reduce healthcare costs and improve access to resources to ensure that health information is equally accessible to all, regardless of their socioeconomic background [Nutbeam, 2000b].

5.2 Social/Environmental Factors

In addition to individual factors, social and environmental elements also have a significant impact on health literacy. Cultural beliefs and practices, shaped by different cultural backgrounds, can affect the uptake and understanding of health information. To improve the effectiveness of health information, health organisations should produce culturally sensitive health communication materials and involve community leaders and cultural influencers [Paasche-Orlow, 2007]. Social support also plays a crucial role in individuals' effective use of health information. Lack of support from family members or the community can affect an individual's ability to seek, understand and use health information. Involving the family in health management and building support networks can enable individuals to better understand and use health information [Nutbeam, 2000a]. Access to health facilities is an important environmental factor that influences health literacy. Limited access or inadequate transportation to health facilities can prevent people from getting the health information and services they need. The expansion of health facilities in underserved areas and the introduction of telemedicine options can improve access to health information and services and remove this barrier. The quality of health-related information sources also significantly influences health literacy. Misleading or inaccurate information from unreliable sources can lead to confusion and misinformation about health issues. Promoting reliable sources of health information and raising awareness about misinformation can help people make more informed decisions about their health.

5.3 Health System-Related Factors

Community norms and attitudes towards health have a significant impact on the behaviour and attitudes of individuals. This shapes health literacy within a community. Implementing community-based health initiatives and working with local organisations can promote positive health behaviours and improve health literacy in the community as a whole. At the health system level, factors related to health communication and care play a critical role in developing health literacy. Clear health communication is essential for patients to understand important health information. Training health professionals in clear communication and health literacy principles can improve interaction and communication between patients and doctors. The quality of health services is also critical to improving health literacy. Health care providers who fail to communicate clearly and engage patients can contribute to limited health literacy. Prioritising patient-centred care and establishing systems that enable effective communication between providers and patients can lead to better health outcomes and higher patient satisfaction. Communication between healthcare providers and patients is an essential component of health literacy. Inadequate communication and insufficient time during medical consultations can hinder the exchange of important health information. Allowing adequate time for the consultation and providing patients with educational materials can facilitate meaningful interaction between patients and health care providers, thereby promoting health literacy. Finally, the availability of health education programmes is critical to improving people's health literacy. Investing in health education programmes, both within the health system and in the community, can provide people with the knowledge and skills they need to make informed decisions about their health.

In summary, health literacy is influenced by a variety of factors ranging from individual characteristics to social, environmental and health system elements. By understanding and addressing these factors, health systems and organisations can create a more inclusive and accessible environment for all people, regardless of their health literacy. Improved health literacy can lead to better health outcomes, higher patient satisfaction and more efficient use of health resources, ultimately benefiting both individuals and communities.

6 Conclusion

Chapter 1 provides a comprehensive overview of health literacy, emphasizing its significance in underserved communities. It underscores the critical importance of recognising and addressing the multifaceted factors that influence health literacy levels, thereby enabling tailored interventions that can make a real impact. The chapter initiates by elucidating the theoretical and conceptual frameworks that serve as the foundation for understanding health literacy. It highlights the central role of these frameworks, offering structured approaches to comprehend and address health literacy challenges across diverse populations and settings. Furthermore, the chapter delves into key theoretical frameworks that are particularly relevant to underserved populations. These frameworks encompass Social Cognitive Theory, Health Behavior Theory, Cultural Competence Theory, and Social Determinants of Health Theory. These frameworks provide invaluable insights into understanding and addressing health literacy disparities within underserved regions. Moreover, the chapter explores a range of conceptual frameworks applicable to underserved communities. These frameworks, including the Health Literacy Framework, Ecological Model of Health Literacy, Cultural Health Capital Framework, Teach-Back Method Framework, and Empowerment Framework, segment health literacy into distinct dimensions, facilitating a systematic approach to addressing health literacy challenges. Throughout the chapter, there is a consistent emphasis on the multitude of factors influencing health literacy. These factors encompass individual-level attributes, social and environmental influences, and health system-related elements. From education levels, language proficiency, and cognitive abilities to cultural

beliefs, social support, and access to healthcare facilities, these factors profoundly shape health literacy levels.

This Chapter 1 underscores the necessity of adopting a comprehensive approach to enhance health literacy in underserved communities. This approach entails recognizing the theoretical and conceptual frameworks guiding health literacy comprehension and intervention. It acknowledges the diverse factors influencing health literacy levels. By effectively addressing these factors, healthcare systems and organizations can establish a more inclusive and accessible environment, ultimately leading to improved health outcomes for all individuals, regardless of their health literacy level. After defining the notion of 'Health Literacy', its concepts, and its importance in underserved communities in this chapter, we are exploring health literacy interventions in SSA in Chapter 2.

Chapter 2

Health Literacy interventions in Sub-Saharan Africa

The following publication contributes to the exploration of how digital health literacy matters and how bridging the gap in rural Africa, which is discussed in this chapter.

I.Ouedraogo, R. Benedikter, M. Some, G. Diallo. "Why digital health literacy matter and how bridging the digital literacy gap could improve access to health, equity in rural Africa?". Africa today Journal Indiana University Press. DOI: <http://dx.doi.org/10.2979/africatoday.69.3.07>

1 Introduction

In the pursuit of better public health, health literacy is a linchpin that enables individuals to make informed decisions about their well-being. The importance of health literacy is particularly pronounced in underserved communities, where access to health information and resources can be limited. SSA countries present a unique landscape for this endeavour. They are characterised by a variety of cultures, languages and socio-economic contexts, all of which contribute to the complexity of health literacy issues. In this chapter, we start with a comprehensive examination of ongoing initiatives and interventions designed to promote health literacy in SSA. Knowing the challenges and diverse needs of this region, we will explore how these programmes address a range of aspects of health care and health education. Community-based initiatives, in particular, are at the forefront of these efforts. Local health workers and dedicated volunteers have played a central role in organising these programmes. The latter cover a wide range of health issues. From infectious diseases to maternal and child health, and from non-communicable diseases to general health education, various mechanisms have been used in these interventions. Community workshops, health camps and outreach programmes have helped to disseminate important health information. By empowering people with knowledge and skills, they enable them to make informed health decisions. In addition, these initiatives have inspired a sense of ownership and community engagement, which ensures the sustainability of these programmes in the long run. In this chapter, we would like to take a closer look at these initiatives and highlight their important role in promoting health literacy and overall well-being among the different population groups in SSA.

2 Overview of health literacy challenges in SSA

SSA is a region characterised by a variety of health literacy challenges. These stem from a diverse socio-cultural landscape, language barriers, limited access to health care, inequalities in health education and the pervasive impact of poverty and socio-economic challenges. Understanding these challenges is critical to developing effective interventions to address the multiple health literacy issues in the region.

2.1 Diverse socio-cultural landscapes and language barriers

The diversity of cultures and languages in SSA poses a major challenge to effective health communication and education. This diversity requires tailored health literacy interventions that incorporate cultural nuances and take into account linguistic diversity to ensure that health information is understandable and accessible to all communities [Sudore, 2006]. For example, initiatives in regions such as the Central African Republic and South Sudan have highlighted the importance of community engagement and working with local leaders to promote health education campaigns in their native language to improve health literacy among diverse populations [Rab, 2023]. Traditional medical practitioners are instrumental in bridging these divides. They often use verbal prescriptions and consultations in local languages, making healthcare more accessible for those with limited literacy. Nonetheless, they encounter challenges like the need to transition to written prescriptions, which introduces additional complexities. [Mokgobi, 2013]

2.2 Limited access to health care and inequalities in health education

Unequal access to health care in urban and rural areas in SSA contributes to inadequate dissemination of health information and services, exacerbating health literacy problems. Limited infrastructure, inadequate health workers and geographical barriers in remote areas hinder the availability and accessibility of health

resources [Labhardt, 2010]. To address this, Non-Governmental Organisations NGO's in various countries such as South Africa, Nigeria, Ghana and Ethiopia have launched mobile health clinics and telemedicine programmes. These programmes ensure that underserved communities receive critical health information and services, improving health literacy and promoting preventive care [Shiferaw, 2012; Akintunde, 2021].

2.3 Impact of poverty and socio-economic challenges on health literacy

Widespread poverty and socioeconomic inequalities in SSA have a profound impact on health literacy and create barriers to education, employment and health care. People in impoverished communities often lack access to the resources and information they need to make informed health decisions, leading to poor health outcomes [Peters, 2008]. Efforts to mitigate this include the implementation of microfinance schemes and community health insurance programmes in countries such as Ghana, which enable marginalised populations to access basic health services and health education, thereby improving health literacy and overall well-being [De La Cruz, 2009].

3 Local community-driven interventions

In SSA, local community-driven interventions have proven to be critical mechanisms for promoting health literacy and improving health outcomes. These interventions rely on the active participation of health workers and volunteers, who play a central role in promoting grassroots initiatives and community engagement in health.

3.1 The role of health workers and volunteers in grassroots initiatives

Health workers and volunteers are key players in implementing grassroots initiatives to improve health literacy. Their involvement in community-based health programmes, health education campaigns and door-to-door outreach have been instrumental in disseminating key health information and promoting health-seeking behaviour at the local level. In regions such as Malawi [Aron, 2023] and Tanzania [August, 2016], for example, community health workers play an important role in providing preventive services, health education and disease management support, contributing to improved health literacy and health outcomes.

3.2 Community workshops, health camps and outreach programmes to raise awareness

Community workshops, health camps, and outreach programs have been proven as effective platforms for raising health awareness and addressing key health issues in local communities. By focusing on promoting preventive care practices, addressing prevalent health problems, and providing essential health services to underserved populations, these initiatives play a crucial role in improving community health outcomes. The African Union's COVID-19 Vaccination Bingwa Initiative¹ aligns with this approach, seeking to enhance health education and literacy by empowering communities with accurate information, engaging activities, and the mobilization of trained young volunteers. Through these concerted efforts, the initiative aims to foster a deeper understanding of COVID-19 and the critical importance of vaccination, thereby promoting literacy in health and disease prevention across the continent.

1. <https://africacdc.org/african-union-covid-19-vaccination-bingwa-initiative-2/>

3.3 Sustainability and empowerment through community engagement

Promoting sustainability and community empowerment is an essential component of local community-led health interventions. Encouraging active community participation, promoting local leadership and involving community members in decision-making processes are key strategies to ensure the longevity and effectiveness of health literacy programmes. For example, community engagement initiatives in countries such as Zambia [Silumbwe, 2019] and Kenya [Davis, 2018] have successfully helped local communities take charge of their health by establishing community health committees, promoting health care and supporting sustainable health practices, resulting in improved health literacy and health outcomes.

4 Global initiatives for health literacy enhancement in SSA

Efforts to improve health literacy in SSA have been greatly enhanced by global initiatives led by prominent international organisations, including the World Health Organisation (WHO) and the United Nations Children's Fund (UNICEF). These initiatives have emphasised the importance of partnerships with local governments and NGO's to implement sustainable interventions to improve health literacy across the region. WHO and UNICEF have been instrumental in implementing projects to improve health literacy in SSA by providing technical expertise, evidence-based strategies and capacity-building programmes [Sharma, 2021]. In particular, WHO's Health Promoting Schools initiative and UNICEF's Child-Friendly Schools programme have successfully integrated health literacy components into their programmes, promoting health education and healthy behaviours among school-aged children in countries such as Nigeria and Ghana [Fernández-Gutiérrez, 2018]. In addition, these global initiatives have underscored the importance of working with local governments and NGOs to ensure the successful implementation of holistic interventions. Collaboration between international organisations and local NGO in countries such as Ethiopia and Rwanda has led to the establishment of community health centres, mobile clinics and health education campaigns that effectively promote access to health services and improve health literacy.

The provision of funding and resources by global health organisations has played a critical role in the implementation of health literacy projects in SSA. Financial support, capacity-building grants and technical assistance from organisations such as the Global Fund to Fight AIDS, Tuberculosis and Malaria and the Gavi Alliance have enabled the development of various health literacy initiatives, including the production of health education materials, training programmes for health workers and the establishment of community health centres. These initiatives have contributed significantly to improved health literacy and health outcomes in several countries in SSA.

By addressing infectious diseases and maternal and child health, global initiatives have placed great emphasis on raising awareness of disease prevention and immunisation, as well as improving access to child health services and optimising paediatric care. These efforts have helped to reduce disease transmission rates, improve maternal and child health, and increase the overall health literacy of mothers and caregivers in the region. In addition, health education initiatives focusing on non-communicable disease control through education have played an important role in promoting lifestyle changes and raising awareness of risk factors for non-communicable diseases, leading to an improvement in the overall health situation in the region.

5 Using technology to promote health literacy

The integration of technology has significantly transformed the landscape of health literacy in SSA. Through various initiatives, digital platforms have been effectively leveraged to promote health education,

provide access to essential health services, and enable informed decision-making about well-being. The utilization of mobile health applications, telemedicine services, and online platforms in local languages has played a crucial role in bridging the health literacy gap and improving overall health outcomes in the region.

The integration of mobile health applications and telemedicine services has significantly enhanced access to healthcare and health-related information [Taha, 2022]. Initiatives like the mHealth Alliance's "Mobile for Reproductive Health (m4RH)" [Feroz, 2020] program and the WHO's "Be He@lthy, Be Mobile" ² campaign have effectively disseminated important health information and fostered a culture of health care in the region.

Furthermore, the development of online health education and awareness platforms in local languages has played a pivotal role in promoting health literacy and community engagement in SSA. Initiatives such as the Health Information for All (HIFA) ³ project and Africa Health Online's "HealthTalk" ⁴ initiative have been instrumental in providing comprehensive health resources and fostering a culture of continuous learning and knowledge sharing in the region.

Additionally, the implementation of digital tools for tracking health information and promoting informed decision-making has revolutionized health management in SSA. Programs like the Global Health Media Project's "Digital Decision-Making Toolkit" ⁵ and the Digital Health Access Initiative's "Health Navigator" ⁶ project have facilitated data-driven health management and encouraged data literacy in communities across the region.

6 Global effort advancing for health literacy in SSA

Global efforts to improve health literacy in underserved African communities are characterised by joint initiatives led by international organisations in collaboration with local partners. These initiatives aim to address the challenges that marginalised populations face in the continent and promote equitable access to critical health information. For example, UNICEF and the African Regional Office WHO ⁷ have jointly developed culturally sensitive materials on child health, nutrition and disease prevention, which are made available in local languages. Their training programmes for health workers, often respected members of underserved communities, ensure that important health information reaches the most remote areas. Similarly, the collaboration between the African Union's Africa CDC and UNESCO ⁸ focuses on addressing health literacy challenges, particularly during disease outbreaks affecting vulnerable populations. Through the use of culturally relevant and accessible messages, this partnership ensures that health information effectively reaches underserved communities. UNESCO Partners In Health's ⁹ involvement strengthens the education aspect by integrating health literacy components into school programmes that empower underserved populations to respond confidently to health crises. By joining forces, these organisations are improving health education in areas of Nigeria with limited access, covering maternal health, disease prevention and treatment adherence. The commitment of these organisations highlights the importance of integrating health education into a broader education system. Through these concerted efforts, health literacy becomes a powerful tool for transformative change that creates a healthier and more equitable African continent in line with the SDG's.

2. <https://www.who.int/initiatives/behealthy>

3. <https://www.hifa.org/>

4. <https://healthtalk.org/About-healthtalk>

5. <https://globalhealthmedia.org/>

6. https://www.healthywa.wa.gov.au/Articles/F_I/Health-Navigator

7. <https://www.unicef.org/wca/reports/nutrition-now>

8. <https://africacdc.org/news-item/unesco-and-africa-cdc-strengthening-community-radio-journalists-on-health-reporting/>

9. <https://unesdoc.unesco.org/ark:/48223/pf0000381728>

7 Health literacy alignment with the SDGs

The Shanghai Declaration on Health Promotion, adopted during the 9th Global Conference on Health Promotion in support of the SDGs [Organization, 2017], emphasises the importance of health literacy as a key priority area for achieving the agenda. Promoting health literacy in underserved communities in Africa is an important step, not only to improve public health, but also to align with the United Nations SDGs. These global goals serve as a comprehensive framework for addressing various challenges and promoting a better future for all by 2030. According to Nata Menabde, Executive Director, WHO Office at the UN [Menabde, 2017] a significant part of the success of the 2030 Agenda depends on improving the health and life expectancy of individuals. A key component of achieving this goal is empowering citizens to better access, understand and utilise information so that they can lead healthier lives. Here are some of the interconnections between health literacy and the SDGs according to Nata Menabde [Menabde, 2017]:

- **SDG 1: No poverty** An individual's response to health information and utilisation of health services is influenced by their level of health literacy. A higher level of health literacy correlates with the adoption of protective measures that can reduce the likelihood of engaging in risky activities such as smoking or unprotected sex. These preventative measures can help to maintain employment and avoid significant health-related expenses.
- **SDG 2: Zero hunger** A comprehensive understanding of basic nutritional habits is crucial for a balanced diet and the prevention of various forms of malnutrition. Parents with health literacy are more likely to prioritise providing their children with the nutrients necessary for healthy growth, thereby increasing the impact of government action to eliminate hunger and malnutrition in various areas.
- **SDG 3: Ensure healthy lives and promote wellbeing for all at all ages** The importance of good health for the promotion of a productive society cannot be overestimated. Those who are healthy are better able to attend school and work and are less likely to go hungry or live in poverty. This recognition of the crucial role of health is reflected in the 2030 Agenda for Sustainable Development, where SDG 3 emphasises the need to ensure healthy lives and promote well-being for all, regardless of age. Health and its social determinants have an impact that goes beyond individual goals and affects all aspects of society. Addressing the challenges posed by the increasing threat of antimicrobial resistance and chronic diseases such as diabetes, heart disease, stroke and cancer requires comprehensive policy support and implementation across different sectors and societal areas. Given the complexity of today's health, social and political problems, a multi-layered response is essential to promote and protect public health. This includes improving government structures to promote healthy public policies and encouraging individuals to prioritise healthier choices. However, for people to make informed choices, they must have a comprehensive understanding of the impact of their decisions.
- **SDG 4: Quality education** Reduced school absenteeism is associated with better student health. A health-conscious school administration can incorporate health education into the curriculum and provide students with the essential skills to promote healthy lifestyles and deal effectively with peer pressure. Positive habits formed during school years can extend into adult life.
- **SDG 8: Decent work and economic growth** Promoting workers' health literacy through workplace health education and the implementation of protective measures in the workplace can foster a favourable working environment. Workers with a good understanding of health literacy can advocate for better and safer working conditions.

- **SDG 9: Industry, innovation and infrastructure** The advent of the mobile revolution provides a unique opportunity to improve health literacy by expanding access to health information and communication. However, governments must ensure that the information provided is of high quality and that any private sector involvement is free from conflicts of interest.
- **SDG 10: Reduce inequalities** Health literacy serves as a tool for marginalised populations to assert their right to health. It can significantly impact the ability of vulnerable communities to ensure that their health-related needs are adequately addressed.
- **SDG 16: Peace, justice and strong institutions** People with higher health literacy can hold their governments accountable when it comes to ensuring access to essential medicines, advocating for universal health coverage, combating air pollutants and abolishing discriminatory laws and practices.

8 Mobile technology penetration in SSA

The number of mobile phone customers in SSA is expected to continue to rise in the coming years, as shown in Figure 2.1. By 2030, this growth is expected to reach almost 700 million, with Nigeria and Ethiopia together accounting for almost a third of the total number of subscribers [System for Mobile Communications, 2023]. Furthermore, mobile penetration in the region is expected to rise to 50% by 2030 [System for Mobile Communications, 2023].

Mobile technology has emerged as a pivotal instrument in advancing health literacy, particularly in rural Africa. The prevalence of mobile phones in the region has become a response to the challenges associated with limited access to health services in remote areas. With a substantial portion of the population now having access to mobile devices, these technologies possess the potential to bridge information gaps and provide vital health knowledge. However, the integration of local languages and voice features has not been fully realized, presenting a barrier to fully harnessing the potential of mobile technology for health literacy in rural Africa. mHealth applications have proven invaluable in delivering essential health information directly to users in underserved areas. These applications offer diverse educational content and guidance on various health topics, including disease prevention, maternal and child health, and chronic disease management. Interactive components within these apps, such as quizzes and self-assessment tools, facilitate engaging and educational learning experiences, particularly in areas with limited formal health education:

8.1 Self-Management Tools and AI-Driven Support

Mobile technology has made significant strides in the development of self-management tools for chronic diseases, as evidenced by the successful implementation of the "WeTel" program in Kenya [Lester, 2010]. This initiative utilizes SMS messaging to ensure adherence to medication regimens among HIV-positive patients, thereby significantly improving health literacy and disease management. Additionally, the integration of AI-driven chatbots and voice assistants, such as Ada¹⁰, has revolutionized the delivery of personalized health information and immediate support to users in remote areas. These AI-driven solutions play a crucial role in enhancing health literacy and facilitating informed decision-making, particularly in regions with limited access to healthcare professionals. However, the effective implementation of AI solutions in underserved populations faces a significant barrier due to the lack of language datasets, especially for Low-Resource Languages (LRL). This deficiency in digital infrastructure and language data affects the accuracy of AI systems in recognizing and synthesizing speech, thereby limiting their capacity to accommodate linguistic nuances, accents, and variations prevalent in these communities. To address this obstacle, a multifaceted approach

10. <https://www.mobihealthnews.com/news/ada-health-launches-swahili-language-version-its-app>

is imperative. Initiatives should prioritize the systematic collection and management of language datasets specific to these resource-poor languages, with active involvement from local communities, linguists, and technology experts. Furthermore, the adoption of data augmentation techniques can expand the dataset size artificially, allowing AI models to learn from a more extensive pool of language samples.

The application of transfer learning techniques is central to this endeavour. Leveraging pre-trained models from well-resourced languages and fine-tuning them with available data from less well-resourced languages can significantly enhance the performance of AI systems, enabling them to respond effectively to linguistic diversity [Myoya, 2023]. Collaborative partnerships between governments, research institutions, technology companies, and local communities play a critical role in addressing language data shortages and ensuring the accuracy of translated content. These collaborations could facilitate the provision of essential resources, promote the exchange of expertise, and encourage the creation of freely available data, tools, and methodologies.

8.2 Program for Audio-Based Health Literacy

Viamo's "Service 3-2-1"¹¹ program employs Interactive Voice Response (IVR) technology to deliver critical mobile health information in local languages. This audio-based approach successfully bridges communication gaps and promotes health literacy among diverse population groups, particularly those with low literacy rates [Hung, 2014]. In conclusion, mobile technology demonstrates significant potential for enhancing health literacy in remote and underserved regions. However, addressing challenges related to language integration and optimal feature utilization is crucial. Initiatives like the "Service 3-2-1" program underscore the commitment to delivering essential health information to underserved communities.

11. <https://viamo.io/services/viamo-platform/>

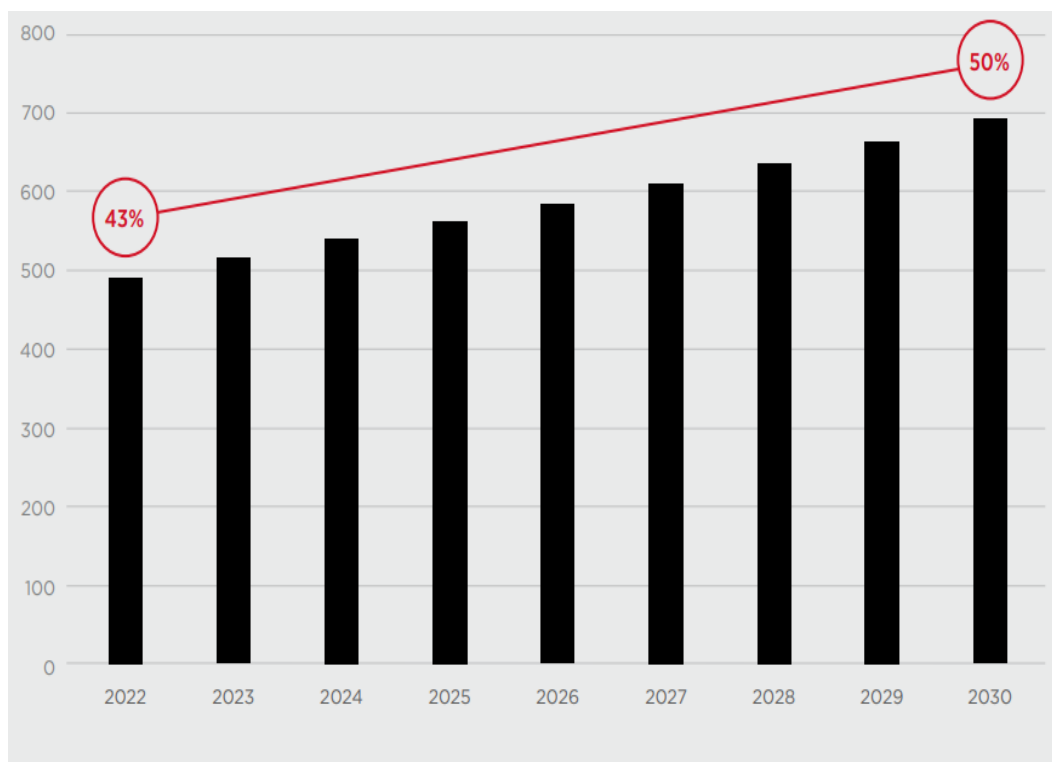


Figure 2.1 – Sub-Saharan Mobile unique subscribers and markets penetration [System for Mobile Communications, 2023]

9 Language integration challenges in mHealth applications in SSA

9.1 Language diversities

As noted by David Adelani [Adelani, 2022], Africa has a great linguistic diversity with over 2,000 languages spoken on the continent. As shown in Table 2.1, these languages, which each have millions or even tens of millions of speakers, reflect the cultural richness and coexistence of different linguistic traditions within African communities. The official languages, which serve formal, legal and administrative purposes, vary from country to country. For example, Kiswahili has official status in Kenya, Tanzania, Uganda and Rwanda. South Africa recognises around 10 languages and Zimbabwe recognises around 14 languages. Ethiopia stands out in that it recognises Oromo, Amharic, Somali, Tigrinya and Afar as official languages, but not Indo-European or Arabic. In some cases, English is used as the language of instruction. National languages, which are recognised due to their widespread use or cultural significance, are of particular importance. Nigeria recognises Hausa, Igbo and Yorùbá as national languages, while Ghana recognises 10 languages. However, about 25 of the 54 African countries do not have defined national languages. Governments generally emphasise the importance of teaching national languages in schools and ensuring their presence on educational and online platforms.

At the community level, local languages are endangered despite their cultural importance, as there are few formal educational opportunities to learn and write them. Although these languages are crucial to regional or community identity, they are not officially or nationally recognised. The inclusion of these languages in mHealth solutions poses a major challenge and consequently impacts health literacy.

Table 2.1 – Demographic and Linguistic Statistics of African Countries: Population Estimates (in millions), Official, and National Languages by David Ifeoluwa Adelani [Adelani, 2022].

N°	Country	Population (M)	Official Language	National / Regional
1	Nigeria	211.4M	English	Hausa, Yorùbá, Igbo
2	Ethiopia	117.8M	Oromo, Amharic, Tigrinya, Afar	Harari, Sidama
3	Egypt	104.3M	Arabic	Egyptian Arabic
4	DR Congo	92.4M	French	Kituba, Lingala, Kiswahili, Tshiluba
5	Tanzania	61.5M		None
6	South Africa	60.0M	English, Kiswahili, isiXhosa, Afrikaans, Sepedi, Setswana, Sesotho, Xitsonga, siSwati, Tshivenda, isiNdebele	None
7	Kenya	55.0M	English, Kiswahili	None
8	Uganda	47.1M	English, Kiswahili	Luganda
9	Sudan	44.9M	Arabic, English	None
10	Algeria	44.6M	Arabic, Berber	None
11	Morocco	37.3M	Arabic, Berber	None
12	Angola	33.9M	Portuguese	Umbundu, Kikongo, Kimbundu, Chokwe
13	Mozambique	32.0M	Portuguese	None
14	Ghana	31.7M	English	Twi, Fante, Dagaara, Dagbani, Dangbe, Ewe, Frafra, Ga, Gonja, Nzema,
15	Cameroon	27.2M	French, English	Cameroonian Pidgin, Fula, Ewondo, Igbo, Chadian Arabic, Camfranglais
16	Madagascar	28.4M	Malagasy, French	None
17	Côte d'Ivoire	27.1M	French	None
18	Niger	25.1M	French	Buduma, Fulfulde, Gourmanchéma, Hausa, Kanuri, Zarma, Songhai, Tamasheq, Tassawaq, Tebu
19	Burkina Faso	21.5M	French	Moré, Bissa, Dyula, Fula
20	Mali	20.8M	French	Bambara
21	Malawi	19.6M	English, Chewa	Tumbuka, Yao, Lomwe, Sena, Tonga, Lambiya, and Nyakyusa-Ngonde
22	Zambia	18.9M	English	Many: (Most spoken: Bemba, Nyanja, Tonga, Tumbuka, Lozi)
23	Senegal	17.2M	French	Wolof, Balanta, Jola-Fonyi, Mandinka, Mandjak, Mankanya, Noon, Pulaar, Serer, and Soninke
24	Chad	16.9M	Arabic, French	None
25	Somalia	16.4M	Somali, Arabic	None

26	Zimbabwe	15.1M	Chewa, Chibarwe, English, Kalanga, Tsoa, Nambya, Ndau, Ndebele, Shangani, Shona, sign language, Sotho, Tonga, Tswana, Venda, Xhosa	None
27	Guinea	13.5M	French	None
28	Rwanda	13.3M	Kinyawranda, French, English, Kiswahili	None
29	Benin	12.5M	French	All, most spoken: Fon, Yoruba, Bariba, Dendi, Mokole, Yom
30	Burundi	12.3M	Kirundi, French	None
31	Tunisia	11.9M	Arabic	None
32	South Sudan	11.4M	English	Dinka, Nuer, Murle, Luo (e.g. Acholi), Ma'di, Otuho, Zande
33	Togo	8.5M	French	Ewe, Kabiye
34	Sierra Leone	8.1M	English, Krio	None
35	Libya	7.0M	Arabic	None
36	Congo public	5.7M	French	Kituba, Lingala
37	Liberia	5.2M	English	None
38	Central African Republic	4.9M	French, Sango	None
39	Mauritania	4.8M	Arabic	Pulaar, Soninke, Wolof
40	Eritrea	3.2M	None (Working languages: Tigrinya, Arabic, and English)	Tigrinya, Beja, Tigre, Kunama, Saho, Bilen, Nara, Afar
41	Namibia	2.5M	English	Afrikaans, German, Otjiherero, Khoekhoegowab, Oshiwambo, RuKwangali, Setswana, siLozi, IKung, Gciriku, Thimbukushu
42	The Gambia	2.5M	English	Mandinka, Pulaar, Wolof, Serer, Jola, Balanta, Hassaniya Arabic, Jola-Fonyi, Mandjak, Mankanya, Noon, Cangin, Dyula, Fula, Karon, Kassonke, Soninke
43	Botswana	2.4M	English	Setswana
44	Gabon	2.3M	French	Fang, Mbete, Myene, Nzebi, Punu, Teke, Vili
45	Lesotho	2.2M	Sesotho, English	
46	Guinea-Bissau	2.0M	Portuguese	Guinea-Bissau Creole, Balanta, Hassaniya Arabic, Jola-Fonyi, Mandinka, Mandjak, Mankanya, Noon, Pulaar, Serer, Soninke

47	Equatorial-Guinea	1.5M	Spanish, French, Portuguese	Annobonese Creole, Igbo, Bube, Fang, Kombe
48	Mauritius	1.3M	None (Working languages: English and French)	None
49	Eswatini	1.2M	Swazi, English	None
50	Djibouti	1.0M	Arabic, French	Somali, Afar
51	Comoros	0.9M	Comorian, French, Arabic	None
52	Cape Verde	0.6M	Portuguese	Cape Verdean Creole
53	São Tomé and Príncipe	0.2M	Portuguese	Forro, Angolar, Principense
54	Seychelles	0.1M	English, French, Seychellois (French-based Creole)	None

9.2 Low resourced languages

In the 90s, NLP underwent a significant change and shifted from rule-based approaches to statistical techniques. Currently, NLP research focuses on only 20 of the world's 7000 languages, leaving a significant majority of languages unstudied in-depth [Magueresse, 2020]. This category of languages, often referred to as LRL's, defies a clear definition and includes attributes such as less researched, low-resourced, less digitalised, less privileged, less frequently taught or low density [Singh, 2008; Cieri, 2016; Tsvetkov, 2017]. In this context, the term LRL refers specifically to languages where the direct application of statistical methods is difficult due to data scarcity.

In SSA, where indigenous languages predominate, there is a major challenge: — the lack of NLP resources and the scarcity of internet-based labelled data. This linguistic context represents a huge obstacle in the field of mobile health applications (mHealth) and, above all, hinders effective measures to promote health literacy. In particular, language integration is a major challenge and hinders the dissemination of important health information in underserved areas [Chitungo, 2021]. The linguistic diversity in SSA, which includes myriad regional languages and dialects, exacerbates this obstacle, as seen in mHealth initiatives that face barriers in providing important content in local languages in countries such as Swahili for east African countries¹². Under-resource languages, particularly in Sub-Saharan Africa (SSA), are often overlooked in NLP research due to the scarcity of high-quality datasets essential for training, assessing, and implementing models [Azime, 2023]. This lack significantly limits the accessibility and impact of digital health platforms for people with lower levels of education. To overcome these challenges, tailored language support mechanisms that prioritise the linguistic needs of local communities need to be put in place. A collaborative approach involving regional language experts, community leaders and technology developers is essential to create language databases that include translations of health content into multiple regional languages and ensure both cultural sensitivity and linguistic accuracy.

Integrating user-friendly language selection features into mHealth applications is critical to improving access to health resources in SSA. The ability to access health information in users' preferred language promotes inclusion and empowers communities to use digital health platforms effectively [Singh, 2007]. In addition, the integration of automatic translation technologies such as NLP and machine learning algorithms promises real-time translation of health content into the different languages of SSA. Prominent initiatives like MomConnect demonstrate the transformative potential of technology in overcoming language barriers and enhancing health literacy in underserved Sub-Saharan African communities. These initiatives translate maternal and child health materials into local languages, integrate cell phone technologies into services, offer free multilingual messages in all 11 official languages, and allow voluntary participation with the option to opt-out at any time [Sibuyi, 2022]. Developing sustainable language support infrastructures in mHealth for low-literate communities in Sub-Saharan Africa prioritizes cultural relevance and linguistic inclusion to overcome barriers, ensuring equitable access to health information and enhancing health literacy.

12. <https://hitconsultant.net/2018/10/10/ada-ghi-app-swahili/>

10 Digital health literacy

These sections delve into digital health literacy, covering its concepts, definitions, and tools used for widespread, emphasizing its evolving importance in modern healthcare and the assessment of individuals' abilities to engage with digital health information effectively. They highlight the evolving landscape influenced by digital technology and underscore the significance of digital literacy within this domain.

10.1 Definition's

The progress of digital technology, encompassing big data, the Internet of Things, artificial intelligence, cloud computing, and wearable devices, has significantly impacted the medical and health domains. The World Health Organization (WHO) [Organization, 2021] and the US Food and Drug Administration (FDA) [Shuren, 2018] define digital health broadly, encompassing the application of digital technology to enhance health outcomes. Digital health goes beyond eHealth by incorporating various elements such as the Internet of Things, advanced computing, big data analysis, and artificial intelligence [Organization, 2021]. As digital health becomes more prevalent, the significance of digital literacy and health literacy in effectively utilizing digital health technologies has gained prominence. Digital literacy involves the effective utilization of information and communication technologies [Kessel, 2022], while health literacy involves understanding health information to promote good health [Nutbeam, 1998]. The emerging concept of digital health literacy combines aspects of civic, digital, and health literacy. Digital health literacy entails the capacity to access, comprehend, and evaluate health information from electronic or digital sources to address health-related concerns [Van Der Vaart, 2017; Information Society and Media European Commission Now known as, 2014]. It extends from the concept of eHealth literacy, initially defined as the ability to seek, comprehend, and utilize health information from electronic sources [Norman, 2006b]. Both digital health literacy and eHealth literacy share similar definitions, differing primarily in the channels through which health information is accessed and processed—evolving from electronic channels to broader digital technology channels. The relationship between digital health literacy and eHealth literacy represents an evolutionary process, with eHealth technology transitioning into digital health technology. According to the WHO report, digital health expands upon and encompasses eHealth [Organization, 2021], leading to increased attention on digital health literacy. Scholars, particularly Norman [Norman, 2006b], have focused on measuring eHealth literacy, proposing it to encompass six core literacies: traditional, health, information, science, media, and computer literacy.

10.2 Measurements

The examination of assessing eHealth literacy has revealed a diverse range of tools and methodologies designed to gauge individuals' competence in navigating health-related information online. Among these tools, the eHealth Literacy Scale (eHEALS) stands out as a prominent instrument initially crafted in 2006 by Norman and Skinner. This eight-item questionnaire serves as a reliable measure of one's ability to access and comprehend health information on the internet, showing moderate stability over time in validation studies [Norman, 2006a]. Additionally, newer instruments such as the eHealth Literacy Scale (eHLS) by Hsu, Chiang, and Yang in 2014 have expanded the evaluation dimensions, appraising functional, interactive, and critical eHealth literacy among college students in Taiwan [Hsu, 2014]. Instruments like the Patient Readiness to Engage in Health Internet Technology (PRE-HIT) have broadened the scope beyond eHEALS, identifying eight distinct factors contributing to eHealth literacy [Koopman, 2014]. Several studies, such as those conducted by Lin et al. [Lin, 2014], Mayberry et al. [Mayberry, 2011], Reiningger et al. [Reiningger, 2013] have employed paired instruments to explore the connections between health literacy, numeracy, computer skills, and internet usage when assessing individuals' proficiency in engaging with digital health information. Additionally, Kayser et al. [Kayser, 2018] introduced a multidimensional tool, the eHealth Literacy Questionnaire (eHLQ), which is grounded in the eHealth literacy framework and underwent initial validity testing. Furthermore, Cheng et al. [Cheng, 2020] contributed to co-designing eHealth and equity solutions through the application of the Ophelia (Optimizing Health Literacy and Access) process. Furthermore, the widespread use of the eHealth Literacy Scale (eHEALS) tool across various studies underscores its versatility and reliability across different populations and languages. It has been employed as a benchmark measurement, to evaluate health outcomes, and in intervention studies aimed at enhancing eHealth literacy [Mitsutake, 2012]. These diverse instruments and methodologies have provided valuable insights into the intricate nature of eHealth literacy assessment. They have shed light on individuals' proficiencies in comprehending and utilizing digital health information, significantly contributing to the evolving landscape of digital health research and practise.

10.3 Evolution of Digital Health Literacy instruments in Web 2.0 dynamics

The concept of eHealth literacy, which is crucial for the use of information and communication technologies (ICT) in healthcare, is gaining in importance worldwide with the increasing use of eHealth. The widespread use of the eHealth Literacy Scale (eHEALS) may be attributed to its emergence as the primary tool available at the time for assessing eHealth literacy. Developed during the early stages of web technology, particularly Web 1.0, the eHEALS addressed the foundational skills required for navigating digital health information [Norman, 2011]. However, with the advent of Web 2.0 and the rise of social media, the landscape of digital health literacy evolved significantly. Several studies address these challenges and provide opportunities for better understanding. Stollefson et al. discuss the complexity of eHealth literacy, emphasising its multifaceted nature that goes beyond traditional literacy skills - a critical consideration as we transition into the era of Web 2.0 [Stollefson, 2011]. Chan and Kaufman propose a framework for assessing eHealth literacy requirements to bridge theory and practise, particularly in the context of evolving Web 2.0 platforms [Chan, 2011]. Xie examines the eHEALS tasks in a wider learning context and highlights the contextual and social nature of learning, which is becoming increasingly important in the Web 2.0 landscape [Xie, 2011]. In addition, van der Vaart et al. question the validity of the eHEALS in light of changing Internet usage patterns and suggest introducing an interactive subscale for social media to capture the nuances of Web 2.0 interactions [Van der Vaart, 2011].

Despite these challenges, the fundamental skills that make up eHealth literacy remain relevant. However, the contexts in which they are expressed, particularly in the dynamic realm of Web 2.0 and social media, lead to new considerations [Norman, 2011]. This presents an opportunity for research and practise to understand and effectively promote eHealth literacy in the evolving digital landscape.

10.4 Digital health literacy in SSA

Digital health literacy in SSA remains a complex issue, largely influenced by differences in technological penetration and education. In 2021, about 39% of the population in SSA had access to the Internet, with significant differences between urban and rural areas. According to the International Telecommunication Union, this digital divide has hindered the widespread adoption of digital health tools and services, especially in remote regions where internet connectivity remains limited. Education and awareness-raising initiatives have been implemented to close this gap, but by 2020, only about 58% of the adult population in SSA had acquired basic literacy skills, according to UNESCO. This highlights the need for tailored education programmes that focus on digital health literacy, with a particular emphasis on the benefits of using telemedicine and other digital health platforms. In addition, linguistic diversity poses a major challenge to the implementation of standardised digital health initiatives. According to the African Academy of Languages, more than 2,000 languages are spoken in the region [Muhammad, 2023]. The availability of digital health resources in local languages is therefore essential for effective communication and understanding across communities.

Despite progress in internet connectivity, large segments of the population, especially in rural areas, continue to face challenges in 2021 due to inadequate infrastructure. Only 28% of the rural population in SSA, which amounts to approximately 600 million people, have access to electricity [Kyriakarakos, 2020]. This has not only hindered the expansion of digital health services but also contributed to a persistent lack of access to basic health facilities.

To address these issues, collaboration between governments, NGO's and private actors is crucial. Initiatives such as the Smart Africa Alliance and the African Digital Health Initiative have been instrumental in building cross-sector partnerships to promote digital health literacy. In addition, implementing data security and privacy measures in line with the African Union's Data Protection Policy¹³ is essential to build trust and promote the adoption of digital health services in the region. By focusing on these strategies and harnessing the momentum of ongoing initiatives, SSA can foster a comprehensive and sustainable digital health ecosystem that meets the diverse needs of its population.

Digital health literacy has become increasingly important, especially in SSA, where mobile phone usage has been on the rise, bringing about significant changes in the healthcare sector [Manyazewal, 2021]. According to the Global System for Mobile Communications (GSMA) mobile subscriptions across SSA will reach 600 million by 2025, representing nearly half of the continent's population¹⁴. This surge in mobile technology has opened up new opportunities for healthcare services, making mobile devices indispensable for health delivery and disease prevention efforts. Despite these advancements, several challenges, such as low digital literacy, limited connectivity, and electricity shortages, have impeded the effective implementation of digital health tools in the region [Holst, 2020]. Consequently, it has become imperative to design digital health solutions that are accessible and user-friendly for individuals with lower digital literacy levels, emphasising the significance of digital health literacy in the development of inclusive healthcare solutions.

The emergence of the COVID-19 pandemic further accentuated the role of mobile technology in healthcare. Healthcare systems swiftly transitioned to providing medical consultations digitally, and mobile phones emerged as crucial tools for the

13. <https://www.au-ibar.org/page/personal-data-protection-policy>

14. <https://data.gsmaintelligence.com/api-web/v2/research-file-download?id=45121567&file=2794-160719-ME-SSA.pdf>

dissemination of health-related information, particularly in underserved communities in SSA. Notably, services like Viamo in Burkina Faso and the Patient Covid-19 project¹⁵ in several African countries capitalized on the power of mobile platforms to bridge the information gap, especially in local languages, benefiting communities with limited resources and literacy rates. These initiatives demonstrated the feasibility and efficacy of technology-driven health interventions, particularly during public health crises in underserved regions.

11 Theoretical and Conceptual Framework of eHealth Literacy

Digital health literacy encompasses multifaceted dimensions that require a comprehensive understanding of the underlying theoretical and conceptual frameworks. These frameworks provide valuable insights into the cognitive, affective, and behavioural aspects of eHealth literacy, contributing to the development of effective interventions and strategies aimed at enhancing individuals' digital health competencies.

11.1 Theoretical Frameworks of eHealth Literacy

The Health Belief Model (HBM) serves as a fundamental cornerstone in exploring individuals' beliefs and perceptions regarding health threats and benefits. In the context of eHealth literacy, the HBM offers insights into users' perceptions of the relevance and effectiveness of eHealth resources in addressing their health concerns [Rosenstock, 1974]. Furthermore, the Social Cognitive Theory (SCT) emphasizes the role of self-efficacy and observational learning in shaping individuals' ability to comprehend and apply eHealth information [Bandura, 1986]. Understanding these theoretical perspectives aids in comprehending users' motivations and attitudes toward engaging with digital health resources. Moreover, the Technology Acceptance Model (TAM) provides valuable insights into users' attitudes and intentions toward eHealth technologies [Davis, 1989]. By examining factors such as the perceived usefulness and ease of use of eHealth platforms, the TAM helps researchers understand the drivers and barriers that influence individuals' adoption of eHealth solutions.

11.2 Conceptual Frameworks of eHealth Literacy

The eHealth Literacy Framework, developed by Norman and Skinner, recognizes that eHealth literacy involves more than just technical skills [Norman, 2006a]. It emphasizes the critical evaluation and interpretation of digital health resources, guiding individuals to navigate the extensive eHealth landscape effectively. This framework encourages a holistic approach to eHealth literacy that integrates elements of traditional health literacy and critical literacy. Additionally, the Digital Health Literacy Conceptual Framework proposed by Paige et al. offers a comprehensive perspective on eHealth literacy, encompassing cognitive, technical, and social components [Paige, 2017]. Recognizing the interdependence of these dimensions, it advocates for a comprehensive approach to eHealth literacy that addresses the diverse needs of individuals seeking health information in digital environments.

Understanding these theoretical and conceptual frameworks is crucial for the development of effective eHealth literacy programs tailored to the diverse needs of individuals seeking health information in digital environments.

11.3 Characterizing e-health Users and Their interactions with e-Health systems

The e-Health Literacy Framework (eHLF)[Norgaard, 2015] serves as a comprehensive roadmap for improving digital health literacy, particularly among underserved populations and those with low literacy. In seven key areas in Figure, it addresses the unique challenges these groups face when using digital health services. For underserved populations with low literacy skills, the framework emphasises the need to process information effectively, actively engage with digital services, feel confident and competent, and be motivated to participate. It also emphasises the importance of ensuring access to reliable and customised digital services that are tailored to their specific needs. For professionals working with these populations, the eHLF also emphasises the importance of having the skills to effectively navigate digital platforms and provide support that is tailored to individual skill levels. Overall, the eHLF provides a structured approach to developing interventions that close the digital health literacy gap and empower underserved and undereducated populations to access and use digital health services effectively.

15. <https://www.patient-covid19.org/contact.html>

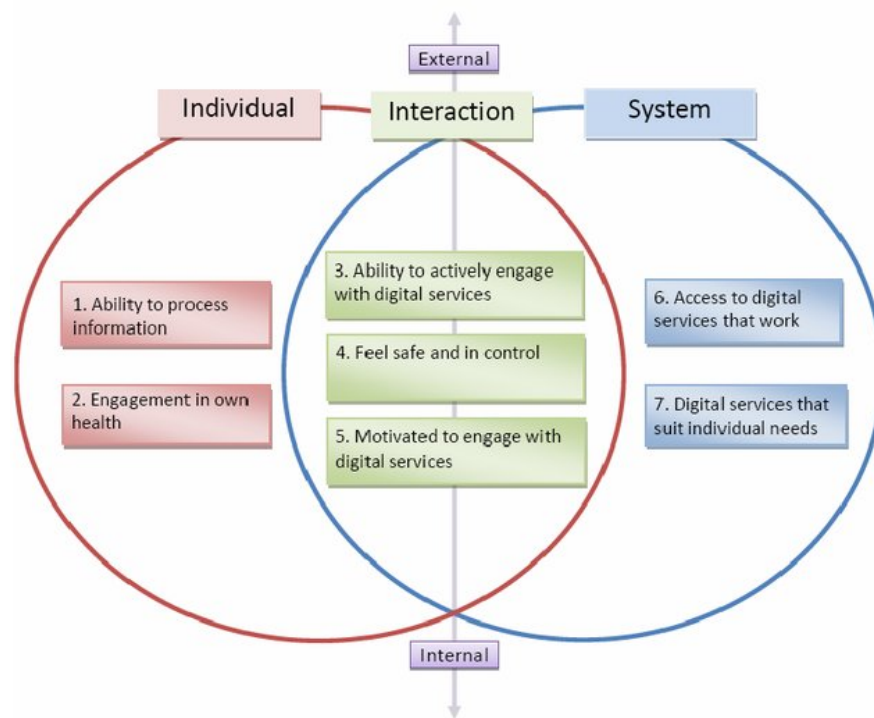


Figure 2.2 – The e-health literacy framework by Norgaard et al.
[Norgaard, 2015]

12 Essential Skills for digital eHealth digital literacy solutions

The model of health literacy developed by Norman et al. includes six key components that are critical to the effective use of digital health resources, as shown in Figure 2.3. Basic reading skills are important for individuals to understand text-heavy digital health content. This enables them to make informed decisions about their well-being and effectively engage with health-related information [Tyner, 2014]. In addition, information literacy is critical as it enables individuals to navigate digital platforms, effectively search for health-related resources and find information that is understandable and relevant to their specific needs. Especially in communities where literacy is not optimal, the ability to find and use relevant health information can significantly impact health outcomes and decision-making processes [National Gambling Impact Study Commission, 1999]. In addition, media literacy is essential for critical analysis of media content, including its social and political context. In areas where literacy is lower, understanding the nuances of media content helps people assess the reliability and impact of health information presented in various digital media [Feuerstein, 1999]. Health literacy, a fundamental component, is essential to understanding health-related terminology and applying health information effectively. Especially in regions with lower literacy, understanding health information and being able to make informed decisions about personal well-being is critical to improving overall health outcomes [Health literacy Report of the Council on Scientific Affairs, 1999]. Equally important is computer literacy, i.e. the ability to use computer technologies and adapt to new digital tools. In communities with lower literacy, access to quality computer resources and information technologies is critical for effective use of eHealth platforms and digital health resources [Logan, 1996]. Scientific literacy is also important for understanding the scientific process and placing scientific findings in context. In lower literacy communities, accessible and understandable health information is essential for understanding complex scientific concepts and research findings so that individuals can make well-informed decisions about their health and well-being [Laugksch, 2000]. The importance of traditional literacy skills cannot be overstated, especially when it comes to adopting digital solutions in Africa, where literacy rates remain relatively low.

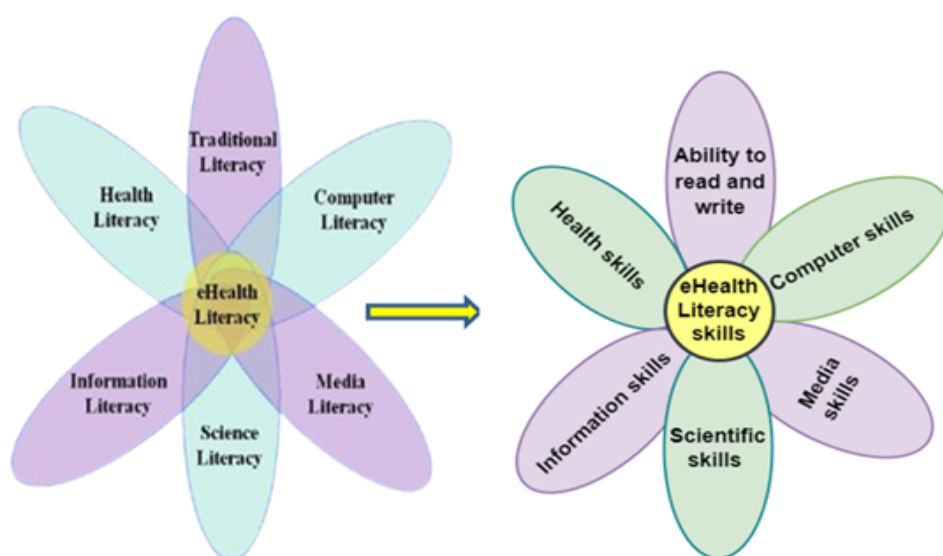


Figure 2.3 – Essential Skills for eHealth literacy by Lily Model [Norman, 2006c]

13 Conclusion

This chapter looks at the important area of health literacy and the remarkable efforts and interventions being made to address the critical health knowledge gap, particularly in underserved communities in SSA. The importance of health literacy cannot be overstated, as it empowers individuals to make informed decisions about their well-being and access important health resources.

Global initiatives driven by international organisations in collaboration with local partners play a critical role in closing this knowledge gap. These initiatives focus on developing culturally appropriate health resources in local languages to ensure equitable access to key health information. Furthermore, these initiatives fit seamlessly with the United Nations *SDG*'s, particularly regarding health, education, gender equality, reducing inequalities and partnerships for sustainable development.

Mobile technology is a game changer, especially in remote and underserved regions. Mobile health apps offer interactive content, self-management tools and innovative AI-driven support. However, there are other challenges, including language integration and under-utilisation of certain mobile features. Overcoming these challenges requires user-centred design, integration of local languages and innovative use of speech recognition technology.

Similarly, AI-powered mobile solutions hold great promise for improving health literacy. They provide personalised health information and bridge the gap in areas with limited access to healthcare professionals. Nevertheless, the lack of language datasets for *LRL*'s remains a significant barrier that requires collaborative efforts to collect, expand and fine-tune data.

Eventually, theoretical and conceptual frameworks such as the Health Belief Model, Social Cognitive Theory and the Technology Acceptance Model offer valuable insights into users' perceptions and attitudes towards eHealth. In addition, the eHealth Literacy Framework and the Digital Health Literacy Conceptual Framework provide a holistic view of eHealth literacy and highlight the multidimensional nature of this construct.

In summary, this chapter emphasises the interconnectedness of health literacy, digital technology, language diversity and individual empowerment. Through these diverse initiatives, underserved populations are equipped with the knowledge and tools they need to make informed decisions about their health, ultimately leading to improved well-being and a more equitable future. The commitment of those involved in these efforts demonstrates a collective determination to create a healthier, more equitable and prosperous world.

After identifying different types of Health Literacy interventions and challenges in SSA, in Chapter 3, we are reviewing the design of mobile health solutions tailored to underserved, low-literate communities.

Chapter 3

Designing mobile health solutions tailored to underserved low-Literate communities.

The following publication contributes to futures literacy as an approach to designing mobile solutions, which this chapter explores.

I.Ouedraogo, I.Ouedraogo, R. Benedikter, M. Some, G. Diallo. "A "Futures Literacy" Framework for understanding the Future of Mobile Health Development in Africa.". IntechOpen. DOI: 10.5772/intechopen.105775

1 Introduction

In an increasingly connected world, the development of mobile solutions for people with different literacy skills has become an important factor in promoting digital inclusion. This chapter addresses the urgent need to create user-friendly interfaces that meet the specific needs of people with low literacy skills and ensure equal access to technological advances. The chapter looks at the intricacies of user interface design, content organisation and user engagement, highlighting the importance of adapting mobile solutions to different user demographics.

With a particular focus on the challenges faced by low literacy users, the chapter highlights the role of human-centred design in promoting a more inclusive and accessible technological landscape. With a holistic approach that incorporates cultural sensitivity, visual clarity and simplified navigation, designers can bridge the gap between digital interfaces and users with varying levels of literacy. In addition, this chapter emphasises the importance of considering the socio-cultural context and linguistic diversity of target user groups, and the need for localised content and culturally relevant design elements.

Through a comprehensive exploration of numerical literacy, visual design and content architecture, the chapter provides existing practical guidelines for creating intuitive and engaging mobile interfaces. By utilising these guidelines, designers can enable seamless interactions, improve comprehension and create a more inclusive digital environment for people with varying levels of literacy. Overall, this chapter serves as a foundational guide for developing mobile solutions that prioritise accessibility, usability and cultural relevance, ultimately helping to promote a more equitable and inclusive digital landscape.

2 Designing a framework for developing mobile health for low-literate users

A. Srivastava et al.[Srivastava, 2021] proposed a set of actionable user interfaces (UI) design guidelines for smartphone applications that are also aimed at users with low reading skills. The framework consists of 13 guidelines categorized into five themes in Table 3.1, namely the input/output model, visual design, content and information architecture, help menu, and human in the loop. In the following sections, we will delve into each topic and provide a comprehensive overview of the synthesized guidelines at the end of each subsection.

2.1 Input/Output Model

In the context of designing a mobile health framework tailored to low literacy users, a key aspect is the input/output model. This section emphasises the importance of incorporating different forms of interaction such as text, graphics and audio components to provide flexible and efficient user support [Idrees, 2017; Idrees, 2019]. The multimodal approach discussed in the UNESCO report [Vosloo, 2018], has been shown to improve accessibility and user engagement. In particular, the guideline 'Use multiple modes of interaction' advocates the integration of various elements such as text, graphics, videos, animations and drawings into the interface to create a natural and user-friendly environment. This approach aims to make the user interface accessible to users with different reading and writing skills, ensuring an inclusive and effective user experience.

2.1.1 Utilize multiple modes of interaction

Research in user interface design has emphasized the importance of incorporating multiple modes of interaction, such as textual, graphical, and audio components, to enhance user support [Idrees, 2017; Idrees, 2019]. Pictorial representations, particularly icon-based interfaces, have proven to be effective and intuitive in conveying information [Medhi, 2006]. While icons can be helpful for non-textual users, relying solely on icons is insufficient, especially for abstract tasks, as their meanings are often best understood when accompanied by textual definitions [Wiedenbeck, 1999]. Audio elements, in the form of auditory icons, have been utilized to present information in a manner analogous to visual icons, offering an organized and intuitive approach for users [Gaver, 1987]. Augmenting text-based interfaces with audio elements or annotations is crucial, especially for low-literate users, as it simplifies complex interfaces and enhances user understanding [Medhi, 2007; Prasad, 2008].

Differentiating between semi-literate and illiterate users is essential in interface design [Findlater, 2009]. Studies have shown that semi-literate users tend to become less reliant on audio over time and may use text to clarify images[Findlater, 2009]. Thus, it is imperative to tailor interface designs according to the literacy levels of users. Previous research has compared various interface types, including text-based, rich multimedia, and spoken dialog systems, highlighting the advantages and disadvantages of each [Ahmed, 2015; Saleh, 2018]. Text-free designs were found to be preferred, especially among illiterate users, as they facilitated faster task completion and required less assistance [Medhi, 2009]. However, the combination of multiple modalities, such as touch interactions, text-free graphical interfaces, and spoken dialog, has also been explored 5[Idrees, 2017;

Idrees, 2019]. The effectiveness of such systems depends significantly on the user's education level [Cuendet, 2013]. Industry reports emphasize the importance of choosing appropriate modalities to present content, as this choice significantly impacts user engagement, confidence, and understanding [Walia, 2020]. By considering these factors and incorporating a combination of modalities, user interfaces can be designed to accommodate a diverse range of users and their literacy levels effectively.

2.1.2 Leverage numerical literacy

Research has highlighted that low-literate users often possess numeracy skills [Medhi, 2006], enabling designers to use numbers for conveying actions and receiving input. Previous studies on financial management systems have shown that users are acquainted with number-based tools like calendars, calculators, and phones, emphasizing the familiarity of low-literate users with numerical interfaces [Parikh, 2002]. Nevertheless, it is crucial to recognize that some users might face challenges in associating numbers with specific actions or navigation tasks. These guidelines as illustrated in Table 3.1 can be considered:

- Utilize Multiple Modalities (G1): Incorporating various modalities such as text, graphics, videos, animations, and drawings within the interface provides flexible and efficient interaction mechanisms, resembling natural user environments. This multimodal approach enhances accessibility and user engagement.
- Incorporate Numbers (G2): Integrate numerical elements into the interface to enhance accessibility. By utilizing numbers effectively, designers can make content more accessible and understandable for users, taking into account the numeracy skills of low-literate users.

2.2 Visual Design

The use of colour in design is not merely an aesthetic choice; it profoundly influences the psychological impact of the interface on users. Studies such as Joshi et al.'s phonebook Rangoli concept demonstrate that colour and icons effectively group contacts, enhancing user interaction [Joshi, 2008]. Research consistently indicates that colour can be strategically utilized to group information, highlight key data, encode relationships in menu hierarchies, and signal changes in-app activity like screen transitions or alerts [Kodagoda, 2010; Prasad, 2008; Tiwari, 2014]. Employing visual cues, such as bold text, varied font sizes, and colour-coding, effectively captures user attention and enhances content comprehension [Doak, 1996].

Various studies have attempted to determine the optimal number of icons, text quantity, or density of other UI elements for low-literate users [Findlater, 2009; Wiedenbeck, 1999; Medhi, 2007]. While text-free based interfaces have been advocated for illiterate users, literate users generally prefer some textual content, considering it a precise communication method [Shakeel, 2002]. The emphasis should be on integrating minimal text while supplementing it with other modalities, ensuring a balance that caters to the needs of both literate and low-literate users [Knoche, 2012]. Unnecessary visual elements can lead to confusion among low-literate users; thus, interfaces should minimize visual clutter, as demonstrated by Ahmed et al. in their interface, which utilized only two icons [Ahmed, 2015].

Moreover, the choice of visual representation matters significantly. Studies such as Medhi et al.'s exploration of different representations of concepts reveal that static drawings are often better understood than realistic photographs [Medhi, 2007]. However, representing actions through static drawings can be prone to misinterpretation, as demonstrated in the example of users misunderstanding a utensil icon as cleaning dishes instead of kitchen-related tasks [Medhi, 2006]. The guidelines related to visual design are presented in table 3.1 as follows:

- Maintain a Minimalist and Clean Interface (G3): Strive for a clutter-free interface by minimizing excessive text, icons, or graphics. A clean design ensures that the user can engage with the content without being overwhelmed, promoting better understanding and user satisfaction.
- Incorporate Visual Cues (G4): Employ visual cues such as colours, text highlighting, and animated messages to direct users' attention to crucial concepts and information. These cues aid in emphasizing important elements and guiding user focus effectively.

2.3 Content and information architecture

In prior research [Kodagoda, 2010; Kodagoda, 2009b], the importance of using plain language for low-literate users has been underscored, emphasizing the need for straightforward vocabulary and avoiding technical jargon, even when presented in the local language [Chen, 2016; Walia, 2020]. Studies have shown that users often struggle with computing-related terms, necessitating the use of everyday language in prompts to ensure understanding [Chand, 2006; Davidoff, 2005; Raza, 2016]. Additionally, studies focusing on information organization have recommended strategies for enhancing visual readability [Doak, 1996]. For instance, limiting the number of concepts on a page, presenting information in simple sentences, manageable chunks, or bullet points can significantly reduce cognitive load [Kodagoda, 2009a; Kodagoda, 2010]. Meaningful contextual

headings and independent pages are crucial for users who tend to scan content word by word [Summers, 2005]. Further details and sub-classifications should be presented using visual or auditory modalities to aid comprehension [Kodagoda, 2010]. Navigating between pages/screens is integral to user experience. Easy, ultra-simplified navigability (G7) is paramount, with forward and backward navigation options being highly recommended [Chaudry, 2012]. Linear or hybrid navigation structures are preferred over complex hierarchical menus, enhancing user engagement and comprehension [Deo, 2004]. Items should be listed on a page instead of multi-level hierarchies to help users identify functions easily, especially since they may lose focus in intricate menus [Ahmad, 2017; Chaudry, 2012]. Scroll bars (G6) should be minimized, as horizontal and vertical scrolling can be less intuitive for low-literacy users [Hill, 2016]. By adhering to these guidelines, interfaces can be made more accessible and user-friendly for low-literate individuals, ensuring a seamless experience. These recommendations draw from extensive research [Kodagoda, 2009b; Medhi, 2011a], emphasizing plain language, effective information organization [Doak, 1996; Kodagoda, 2009a], simplified navigation structures [Chaudry, 2012; Deo, 2004], and the avoidance of non-intuitive interface elements [Agrawal, 2013; Hill, 2016].

2.4 Help Menu

Prior studies have underscored the vital importance of integrating a consistent and easily accessible help feature within applications [Chen, 2016; Medhi, 2006]. This support should extend to providing initial guidance to users upon starting the application, accompanied by incremental tutorials, videos, demos, and instructions to facilitate comprehension and learning [Font, 2017; Molapo, 2013; Sherwani, 2009]. Various forms of assistance, such as help pages, FAQs, tooltips, and tutorials, can be instrumental [Walia, 2020]. To enhance user engagement, instructions should be contextually embedded and offered in a short, simple, and step-by-step manner, avoiding overwhelming linear instructions [Chen, 2016; Raza, 2016]. To address literacy barriers, interactive audio instructions have been proposed as an effective solution [Medhi, 2007]. Research studies, such as the one conducted by Smyth et al. [Smyth, 2010], have demonstrated that voice instructions, especially when delivered by animated agents, foster a strong user affinity towards the system. Visual characters on-screen enhance users' ability to connect the system's voice with a relatable personality [Kodagoda, 2010]. These interactive interactions not only aid users in understanding correct interface usage but also serve as valuable feedback mechanisms, informing users of their actions and ensuring they are following the correct procedures [Chaudry, 2012; Weiss, 2003]. Furthermore, well-designed feedback mechanisms that distinguish between technical/design errors and human errors can significantly reduce user frustration. Clear and jargon-free resolutions for errors, such as providing specific guidelines for input formats or validating user-entered values through audio-based confirmation, can enhance user confidence and mitigate challenges associated with low literacy levels [Chen, 2016]. In the evolving landscape of smartphone applications, the integration of a consistent and easily accessible help feature (G8) is paramount. Additionally, instructions should be delivered in a short, simple, and gradual manner (G9) to facilitate user understanding and retention. Furthermore, incorporating audio and video help options (G10) can effectively address the hurdles arising from low literacy levels, promoting a more inclusive and user-friendly experience. These guidelines draw upon research findings [Wiedenbeck, 1999; Sherwani, 2009; Taoufik, 2007] [Weiss, 2003] to enhance user support in applications.

2.5 Human in the loop

The literature highlights the importance of involving the target population and different stakeholders in the design process, using their unique contexts [Joshi, 2008; Ninsiima, 2015]. These studies clearly show the importance of involving these groups and understanding their perspectives. Let us now turn to the factors that influence the acceptance and use of technology.

2.5.1 Adopt a culturally responsive design

Numerous studies highlight the central role of users' cultural identity in shaping their perceptions, preferences and understanding of different aspects of computing environments [Evers, 1999; Marcus, 2000; Heukelman, 2009; Reinecke, 2011]. For example, many users are unfamiliar with concepts such as files, folders, envelopes and clipboards in an office environment. Transferring these metaphors to the components of UI may affect their comprehensibility. Heukelman et al [Heukelman, 2009] suggested the metaphor of the African village as an alternative to the office metaphor and emphasised the need for culturally relevant metaphors in user interfaces. Research has shown that culturally specific interfaces can greatly improve usability [Heukelman, 2009]. Lalji and Good [Lalji, 2008] observed instances where users misinterpreted musical notes (meant to represent the radio) as birds, highlighting the importance of culturally appropriate icons for user recognition [Findlater, 2009; Medhi, 2007].

It is crucial to adapt icons to the cultural context of the target users rather than assuming universal recognition [Chipchase, 2008; Findlater, 2009; Lalji, 2008; Medhi, 2007]. Kim and Lee [Kim, 2005] have shown that semi-concrete icons are preferred to concrete icons because the latter may be associated with real objects whose interpretation is different in different cultures.

Moreover, the meanings associated with other elements of UI such as colours [Parikh, 2002], graphics and classification taxonomies [Walton, 2002] are often culturally determined. Several reports emphasise the importance of including culturally relevant content to build the confidence of low-literacy users and promote their acceptance of the technology [Chen, 2016].

In addition, it is important to consider that not all users of an application are proficient in a common language such as English. Therefore, support for local languages [Ahire, 2014; Ahmed, 2013; Medhi, 2011b] is essential for both text and audio interfaces. This localised approach ensures that users can interact effectively with the application, promotes integration and increases user activity.

2.5.2 Enable customization

Users within the same application demographic who share a common cultural and linguistic background often have remarkably different needs [Raza, 2016]. Given this diversity, customisation emerges as an important strategy for creating spaces that are more human, familiar and comfortable. For example, Singh et al. [Singh, 2016] developed an early warning system for fishermen in Maharashtra, India. In this system, users were able to store their preferences and thus allowing to disseminate customised content based on their specific needs. This customisation not only improves functionality, but also adds an element of pleasure and utility, making the application an effective navigation aid [Cooper, 2007]. Catering to individual preferences enables applications to provide a sense of familiarity and personalisation, increasing user satisfaction and engagement.

2.6 Leverage human facilitators

Many studies [Wiedenbeck, 1999; Hill, 2016; Prasad, 2008] have traditionally looked at the design of user interfaces for literate users, focusing on individual mobile phone use. However, Ahmed et al. [Ahmed, 2013] offer an innovative perspective by emphasising that interactions between people and technology are embedded in an 'ecological' model. According to this model, users collaborate with others and use their social and environmental resources to overcome the challenges associated with illiteracy. Friends, family members, external networks [Chand, 2006] and available resources [Taoufik, 2007] become indispensable support systems that enable users to overcome the obstacles posed by illiteracy. The integration of human intermediaries into the system can play a crucial role by familiarising potential users with different scenarios [Medhi, 2011b] and UIs, helping them to overcome initial hesitation and barriers to adopting a new application or device [Walia, 2020]. The guidelines concerning the Human Facilitator are outlined in Table 3.1 below:

- Start by considering users' cultural identity (G11), level of education, and technological experience while developing applications.
- Enable users to personalize the content, layout, and overall functions of the application to meet their specific needs (G13).
- Furthermore, ease the intimidation stemming from the application's complexity by incorporating human helpers (G12) within the system to effectively aid individuals with lower literacy.

Table 3.1 – Framework for designing mobile phones for low literate people.

Topic	Guidelines	Actionable Guidelines
Input/Output Model	Guideline 1 (G1) Guideline 2 (G2)	G1 Use multiple modes of interaction: Support the application with multiple (input/output) media text, audio, video, etc. for easy understanding G2:Use your numerical competence: Use numbers (wherever possible) to convey information and get input, as users with low literacy skills can handle numbers
Visual Design	Guideline 3 (G3) Guideline 4 (G4)	G3: Ensure a minimalist, clean interface: Minimise the use of text and visual components on each screen to optimise white space, reducing interface complexity and feature overload G4: Include visual clues: Introduce bold text, highlighting and colour coding as visual cues to grab users' attention

<p>Content & Information Architecture</p>	<p>Guideline 5 (G5) Guideline 6 (G6) Guideline 7 (G7)</p>	<p>G5: Avoid technical jargon: Use understandable (every day) words and minimise domain-specific and technical jargon, as these are difficult for less educated users to understand</p> <p>G6: Break down information within and between screens: Limit information on a page to reduce scrolling and improve visual readability. Present information in a concise format and use small paragraphs or bullet points wherever possible.</p> <p>G7: Simplify the navigation structure: Minimise menu hierarchies. Prefer linear navigation or flat menu hierarchies to reduce navigation complexity</p>
<p>Integrate Help</p>	<p>Guideline 8 (G8) Guideline 9 (G9) Guideline 10(G10)</p>	<p>G8 : Assist in using the application: Ensure that the help option is easily accessible from any screen and integrate well-designed feedback mechanisms to enable more autonomous use.</p> <p>G9: Include short, simple instructions in the help menu: Summarise instructions in a short, step-by-step, simple way and avoid instructions with multiple steps, as users may not pay attention right away.</p> <p>G10: Use audio and video tutorials: Prefer audio or video tutorials over text instructions in the help menu to make the help content easily accessible.</p>
<p>Human in the Loop</p>	<p>Guideline 11 (G11) Guideline 12 (G12) Guideline 13 (G13)</p>	<p>G11: Introduce a culturally appropriate design: Incorporate local language support and culturally appropriate UI elements such as icons, graphics, colour schemes, etc. It is cultural identity that shapes user perception, understanding and preferences.</p> <p>G12: Use human intermediaries: Integrate human intermediaries (family, peers, community, designated professionals, etc.) into the overall system design to familiarise users with possible scenarios and user interfaces to easily overcome barriers to use.</p> <p>G13: Enable customisation: Save user preferences for the content, layout and other settings of the application, as this makes the space more human, familiar and enjoyable</p>

3 Future literacy approach for design mobile solutions

This section delves into an exploratory study aimed at applying the Futures Literacy (FL) approach to guide the development of mobile health (mHealth) solutions in Africa [Ismaila Ouedraogo, 2022]. Stressing the importance of proactive planning in addressing regional health challenges, the study emphasizes FL's role as a framework for futures literacy, fostering innovative and sustainable mHealth interventions. By examining both the theoretical foundations of FL and its practical implications in health system design, the research offers valuable insights into FL's potential to transform healthcare in Africa's future. Additionally, the study highlights the integral and comprehensive nature of the systematic process within the FL approach, which involves integrating local contexts, anticipating future scenarios, promoting active participation, and establishing ongoing evaluation mechanisms. Moreover, the study [Ismaila Ouedraogo, 2022] emphasizes the integral nature of a comprehensive, step-by-step process within the FL approach, integrating the local context, anticipating future scenarios, fostering active participation, and ensuring continuous evaluation.

3.1 Futures literacy concept

Literacy, originally associated with the basic ability to read and write, has evolved considerably to encompass broader competencies, including numeracy and the use of information and communication technologies for effective participation in society [Souchier, 2012; OECD, 2012]. As science and technology have advanced, this development has led to a re-evaluation

of the concept, particularly in light of the changing nature of knowledge and skill-based techniques associated with complex devices [Plante, 2019].

In the context of the evolving landscape of information technologies, the concept of future competence has emerged to refer to the ability to anticipate and proactively shape impending change [Miller, 2018]. As communication functions move beyond processing traditional symbols and interact directly with the material technology of devices, the ability to interact effectively with technology becomes critical to accessing information and fostering social engagement [Plante, 2019]. This underlines the need to conceive of FL in terms of actively managing and shaping future developments.

UNESCO has been at the forefront of defining and promoting FL as a crucial skill that enables individuals to understand the role of the future in shaping their present perspectives [Miller, 2013]. This concept is comparable to the importance of reading and writing and makes it clear that it is a fundamental skill that can be learned by all people and is essential.

3.2 Futures Literacy initiatives

To promote the development of FL, UNESCO has initiated numerous Futures Literacy Laboratories (FLL) since 2012, targeting a wide range of participants from different sectors such as governments, international organisations and professional associations [Miller, 2013]. These laboratories serve as practical platforms for participants to enhance their ability to imagine and use the future in different contexts, resulting in an immediate and tangible impact on their decision-making capacity in the present.

In the practical phases of FLL, participants are guided through a series of structured exercises. The first phase focuses on improving temporal and situational awareness, encouraging participants to explore their ideas about the future and imagine their desired outcomes without immediately worrying about practical implementation [Miller, 2007]. The second phase involves a creative storytelling game that encourages participants to challenge and change their underlying assumptions about the future, thus expanding their conceptual framework and imagination [Forte, 2020]. In the final phase, participants are encouraged to translate their insights into actionable strategies and decisions, developing a deeper understanding of how their vision of the future shapes their current actions and decisions. Through this process, participants are empowered to effectively address the challenges of the present and align their efforts towards the shared goals of resilience, well-being and peace [Forte, 2020]. Through these initiatives, UNESCO's FL programme has become a central platform for promoting a deeper understanding of the future and its impact on the present.

3.3 Futures literacy approach to design inclusive mobile solutions

The Futures Literacy FL approach can serve as a powerful framework for developing inclusive mobile solutions, especially in the context of addressing various societal challenges. By using the principles of FL, designers can proactively anticipate and understand the evolving needs and preferences of different user groups. This process is about developing a deep understanding of potential future scenarios and their implications for the development of mobile solutions that meet the diverse needs of individuals and communities.

Comprehensive understanding of the context: At the beginning of the design process, a thorough investigation and analysis of the local health landscape is crucial [Aranda-Jan, 2014]. This includes consideration of factors such as existing infrastructure [Aranda-Jan, 2014], available resources, prevailing health challenges and the specific needs of different communities in the region [Labrique, 2013]. This comprehensive understanding serves as a solid foundation for the development of tailored mHealth solutions that effectively address the unique challenges in different African contexts.

Creation and analysis of future scenarios: Engaging a broad range of stakeholders, including health professionals, policymakers, technology experts and community representatives, is central to creating and analysing potential future scenarios [Unwin, 2017]. This process should include a critical examination of emerging technological trends, social dynamics and anticipated changes in health needs [Mars, 2012] to ensure that the mHealth solutions developed remain relevant and adaptable to the evolving needs of local populations.

Strategic planning The identification of potential challenges and opportunities must be followed by strategic, forward-looking planning that takes into account the various contingencies and challenges [Källander, 2013b]. This includes proactive measures to address potential barriers to the successful integration of mHealth [Meskó, 2022], as well as leveraging potential enablers to maximise the positive impact of these technologies within the health system.

Inclusive co-creation and participation: Encouraging the active participation and co-creation of local communities, health professionals, policymakers and technology developers is critical to ensure that the mHealth solutions developed are inclusive and take into account the diverse needs and preferences of target groups [Mars, 2012]. By fostering a collaborative environment, the development process can leverage collective expertise and insights, resulting in solutions that are culturally sensitive and easily adopted by the communities they are intended to serve.

Continuous assessment and iterative development: Finally, the process of developing mobile health solutions must include a framework for continuous evaluation and iterative development [Labrique, 2013]. Regular assessments and feedback mechanisms enable monitoring of the impact of implemented mHealth solutions [Källander, 2013b]. It also allow timely adjustments and improvements to the design in response to evolving health needs, technological advances and new challenges. This iterative approach ensures that mHealth solutions remain effective, sustainable and consistent with the overall goals of improved access to health care and better outcomes in the African context.

Overall, by embracing the FL approach, designers can proactively shape the future of mobile solutions, fostering inclusivity, accessibility, and user-centric design principles that empower and benefit a wide range of individuals and communities.

4 User-centred design approach to design inclusive mobile solutions

According to Jackson [Jackson, 1999], ethnographic research activities can be classified into three distinct phases: pre-field, fieldwork, and post-field. In the context of this thesis, the utilization of ethnographic methods complemented the User-Centered Design (UCD) process, providing valuable insights into the users, their tasks, and their surrounding environment. The relationship between ethnography and UCD is illustrated in Figure 3.1. User-centred design plays a central role in the development of mobile health solutions in SSA. It ensures that the specific needs and preferences of target users are central throughout the design process [Jing, 2021]. This approach involves conducting thorough user research and actively engaging representatives of the less educated population to enable a comprehensive understanding of the health-related challenges in the region [Sanders, 2008]. Through interviews, focus groups and usability testing, designers can gather valuable insights and direct feedback from users to ensure the relevance and effectiveness of the mobile health solution [Gulliksen, 2003]. In addition, consideration of cultural context is critical in user-centred design, as it allows solutions to be developed that are consistent with the cultural values, beliefs and practices of the local population [Putnam, 2009]. Further, including the languages spoken by the target users is also crucial. This ensures that health information is easily accessible and understandable, which in turn promotes user engagement and trust in the mobile health solution [Källander, 2013b]. Given the technological limitations prevalent in the region, designers need to adapt the mobile health solution to work seamlessly on low-cost devices and in areas with limited internet connectivity to ensure wider accessibility and usability [Laplante, 2004].

4.1 Understanding the users

The first step in UCD is to deeply understand users and their needs. This involves conducting user research, which may include interviews, surveys, observations, and other research techniques. The aim is to gain insights into users' goals, tasks, preferences, and challenges. By empathising with users, designers can develop a clear understanding of their context and motivations.

4.2 Identifying user requirements

Based on user understanding, designers can identify and prioritise user requirements. This involves translating the insights gained from user research into concrete design requirements. User requirements define what the design should do, what features it should contain, and how users should like it overall. The user requirements form a basis for the design process and serve as a decision-making aid.

4.3 Prototype design

Once user requirements are established, designers create prototypes to visualise and test their design ideas. Prototypes can take different forms depending on the project, from low-fidelity sketches and wireframes to interactive mock-ups or functional prototypes. The key is to create representations of the design that users can interact with and provide feedback on. Prototypes allow designers to explore and refine design concepts before investing significant resources in development.

4.4 Evaluation

The evaluation phase gathers user feedback on prototypes through usability testing, user feedback sessions and other evaluation methods. The aim is to assess how well the design meets users' needs and to identify any usability issues or areas for improvement. By involving users in the evaluation process, designers can gain valuable insights into the effectiveness, efficiency, and satisfaction of the design. This feedback is used to refine the design and make iterative improvements.

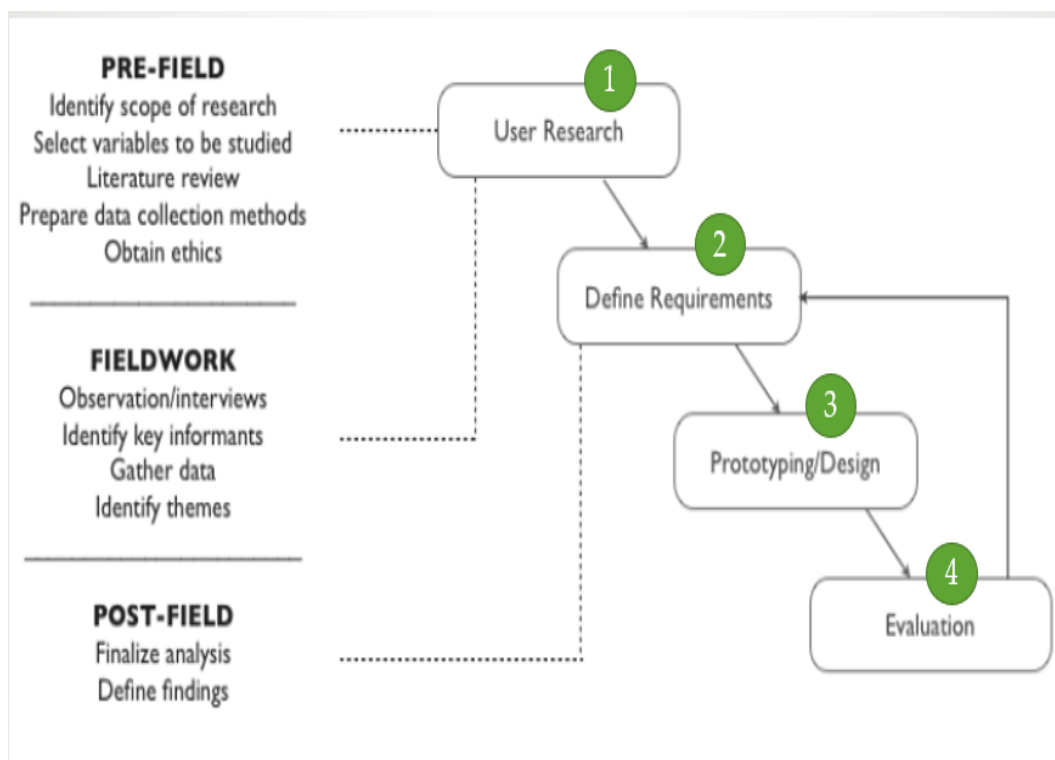


Figure 3.1 – User-centred Design approach(adapted from [Min, 2013])

5 Conclusion

To summarise, this chapter has highlighted the critical considerations and best practices for developing mobile solutions that meet the needs of people with different levels of education. By emphasising the importance of user-centred design, cultural sensitivity and intuitive interface elements, the chapter highlights the central role of inclusive design in promoting digital accessibility and equity.

Through an in-depth analysis of interface design principles, content organisation strategies and the integration of cultural relevance, the chapter provides actionable insights for creating user-friendly and culturally appropriate mobile interfaces. By prioritising visual clarity, minimalism and the integration of different modalities, designers can create interfaces that cater to users of different language levels and cultural backgrounds, promoting a more inclusive and engaging user experience.

In addition, this chapter has highlighted the importance of context-specific design elements and content localisation to ensure effective communication and user engagement. By taking into account the cultural diversity and linguistic nuances of target user groups, designers can create interfaces that speak to users on a personal and cultural level, ultimately leading to greater user satisfaction and long-term engagement.

By integrating the principles of future literacy and user-centred design, designers can proactively anticipate and address the evolving needs of different user groups, helping to develop sustainable and impactful mobile solutions. By fostering collaboration, empathy and continuous assessment, designers can create mobile interfaces that not only meet the immediate needs of low-literate users but also enable them to navigate the digital landscape safely and effortlessly.

This chapter serves therefore as a comprehensive guide to developing inclusive, accessible and culturally relevant mobile solutions and highlights the importance of taking into account the specific needs and preferences of different user groups. Through a user-centred and culturally sensitive approach, designers can play a crucial role in bridging the digital divide and fostering an environment of technological inclusion and empowerment.

Following the state-of-the-art review of the identification of health literacy interventions in Chapter 2 and the design of mobile health solutions tailored to underserved, low-literate communities in Chapter 3, we are assessing in Chapter 4, the effectiveness of mobile-based local language and voice technology in improving health literacy among underserved communities.

PART II: CONTRIBUTIONS

Chapter 4

Effectiveness of Mobile-Based Local Language and Voice Technology

The contributions to this chapter have been discussed in the following publications:

I.Ouedraogo, R. Benedikter, M. Some, G. Diallo. "Improving health literacy in rural Africa through mobile phones: a systematic literature review.". *Journal of Health Informatics in Africa*. DOI: <https://doi.org/10.12856/JHIA-2021-v8-i1-312>

Ouedraogo I, Some BMJ, Oyibo K, Benedikter R and Diallo G (2022) Using serious mobile games to improve health literacy in rural Sub-Saharan Africa: A literature review. *Front. Public Health* 10:768252. doi: 10.3389/fpubh.2022.768252

Under review

I.Ouedraogo, M. J. Some, K.Oyibo R. Benedikter , et G. Diallo. "Evaluating a phone-based Interactive Voice Response system for reducing misinformation and improving malaria literacy ".*Information Technology for Development*.

1 Introduction

The increasing use of mobile technologies and their incorporation with local voice capabilities have had a significant effect on addressing healthcare challenges, especially in underserved communities globally. This chapter examines the design and implementation of mobile health solutions customized for the specific needs of populations with low literacy levels. It emphasizes the significant impact these initiatives could have in Burkina Faso.

Through two compelling case studies, this chapter highlights the critical role of technology-enabled interventions in improving health literacy, promoting accessibility and ultimately improving health outcomes for marginalised communities in Burkina Faso. Through these case studies, the chapter highlights the particular challenges faced by underserved populations in Burkina Faso, where limited access to health information and resources remains a significant barrier to improved health outcomes. By exploring the innovative use of local languages, user-friendly interfaces and community engagement tailored to the specific context of Burkina Faso, the chapter aims to highlight the key strategies and design principles that are essential for the successful implementation of mobile health solutions in this country. Integrating local languages and language technologies not only improves accessibility but also promotes cultural relevance and ensures that vital health information is understandable and actionable for people with limited literacy skills in Burkina Faso.

The chapter also addresses the critical role of user-centred design in the design of technology-enabled health solutions and emphasises its importance in the context of Burkina Faso. By foregrounding the needs and preferences of target groups, these initiatives can effectively bridge the information gap, empower users and promote a deeper understanding of key healthcare concepts in the specific cultural and linguistic context of the region. In addition, this chapter explores the importance of collaboration among stakeholders, including local communities, healthcare providers and technology developers, for the successful implementation and sustainability of mobile health initiatives in Burkina Faso.

Overall, this chapter serves as a comprehensive examination of the design and application of mobile local voice and speech technology in health interventions in Burkina Faso. By delving into the specifics of the case studies in the context of Burkina Faso, the chapter aims to provide valuable insights into the transformative potential of technology-enabled solutions in addressing health inequities and promoting equitable access to critical health information for underserved populations in this country.

2 Presentation of case studies in Burkina Faso

Burkina Faso was selected as study areas because of the presence of underserved communities that face challenges such as low literacy rates and various language barriers. This selection highlights the need for tailored health literacy interventions that can meet the specific needs of these communities.

2.1 Burkina Faso

Located in West Africa, Burkina Faso faces enormous health challenges, particularly in underserved communities where literacy rates are only 34.6%¹ for the total population. Language diversity is a significant barrier to accessing vital health information and exacerbates inequalities in health outcomes across communities.

Burkina Faso was selected as the focal point for this health literacy study due to the pressing need to address challenges faced by underserved communities, particularly concerning low literacy rates and linguistic diversity, which create significant barriers to accessing essential health information. The study aims to develop customized health literacy interventions that are culturally sensitive and easily understandable for communities with limited literacy skills. Additionally, the research investigates the potential of mobile technology to improve the accessibility of health information services. By concentrating on Burkina Faso, the research endeavors to promote health equity and empower underserved communities to actively engage in making informed decisions about their well-being.

Ultimately, the research aims to promote health equity and empower underserved communities in Burkina Faso to make informed decisions about their well-being. Access to accurate and comprehensive health information is critical to improving health literacy and promoting better health outcomes in these vulnerable communities.

2.2 Languages

The study revolves around enhancing health literacy in West African languages, specifically focusing on Fula in Guinea, Moré, and Dioula (or Jula) in Burkina Faso. The primary aim is to address health literacy challenges by considering the nuanced dynamics of local and national language use. Recognizing the pivotal role of linguistic and cultural factors in health

1. <https://fondation.loccitane.com/actions/empowering-women/rural-womens-literacy>

communication, the research targets the imperative task of bridging language barriers to promote effective health literacy in diverse linguistic landscapes.

Mossi, known as Mooré or Mòoré, is a West African language spoken primarily by the Mossi people, predominantly in Burkina Faso. The language also has speakers in Benin, Togo, Mali, Ivory Coast, and Ghana. With approximately 7.6 million native speakers², Mossi holds a significant linguistic presence in the region. Impressively, about 48 percent² of Burkina Faso's population can communicate in Mossi, highlighting its widespread usage and importance within the country. In Burkina Faso, the Moré language presents difficulties due to its various dialects, requiring tailored materials for health education.

Dioula, also known as Jula, is a Western Mande language spoken in countries such as Burkina Faso, Ivory Coast, Mali, and others, making it a vital linguistic link across these West African nations. With an estimated 12.5 million speakers³, Dioula/Jula significantly contributes to the cultural and communicative fabric of the region. Its widespread use highlights the importance of addressing linguistic and health literacy challenges in Dioula-speaking communities, emphasising the need for tailored interventions to promote effective health communication and understanding among approximately 12.5 million people.

Efforts to address health literacy challenges in these underserved communities include assessing education levels, community engagement, utilizing oral communication methods, translating materials into specific languages and dialects, and ensuring cultural competency. These initiatives are particularly crucial as Fula, Moré, and Dioula collectively represent a substantial percentage of the overall population in the respective regions. By adapting health communication to the linguistic and cultural context of these communities, the goal is to effectively improve health literacy, recognizing its significance for the well-being of a significant portion of the local population

Efforts to address health literacy challenges in these underserved communities include assessing education levels, engaging the community, using oral communication methods, translating materials into specific languages and dialects, and ensuring cultural competency. By adapting health communication to the linguistic and cultural context of the Fula, Moré and Dioula communities, initiatives can effectively improve health literacy and thus contribute to better health outcomes in these regions

3 Review of mobile solutions used to enable Health Literacy in Africa: case study 1)

3.1 Context

Mobile technology has emerged as a transformative force within the realm of healthcare. Particularly, the rise of mobile connectivity in Africa has led to an increasing focus on utilizing mobile technology to address healthcare challenges. With the number of smartphone owners nearly doubling between 2016 and 2020, reaching a penetration rate of 55%, mobile health (mHealth) initiatives have garnered significant attention for their potential to enhance healthcare accessibility and delivery [Diallo, 2018]. Despite these advancements, the persistence of low health literacy remains a critical concern, particularly in rural areas. Limited access to healthcare information and resources significantly hampers the ability of communities to make informed health decisions, leading to poorer health outcomes and exacerbating existing healthcare disparities [Haenssgen, 2017]. Low health literacy has far-reaching implications, contributing to a lack of engagement with healthcare services and suboptimal health management. This issue disproportionately affects vulnerable populations, including older adults, minority groups, and individuals with lower socioeconomic status, perpetuating disparities in healthcare access and outcomes [Bank, 2021]. Limited access to comprehensible health information impedes communities' ability to adopt preventive health practices and engage in timely interventions, highlighting the urgent need for effective communication strategies to bridge the health literacy gap [Bank, 2021].

Mobile solutions have emerged as powerful tools for delivering essential health information and services to underserved populations. Through various applications and initiatives, mobile technology facilitates the direct dissemination of critical health information, including disease prevention, maternal and child health guidance, and chronic disease management [US Health Resources Services Administration, 2017]. Projects such as "WeTel" program in Kenya have successfully leveraged SMS messaging to support HIV-positive patients in adhering to medication regimens, showcasing the potential of mobile technology in enhancing disease management and health literacy [World Health Organization, 2009]. Additionally, the integration of AI-driven chatbots and voice assistants, such as Ada, has revolutionized the accessibility of personalized health information, empowering users in remote areas to make informed decisions about their health [GSMA, 2019]. By leveraging mobile solutions, communities can access tailored and easily understandable health information, leading to improved health outcomes and increased engagement with healthcare services.

2. <https://www.tumblr.com/jeparletoutesleslangues/164179146583/mossi-known-in-the-language-as-moor%C3%A9-also-m%C3%B2or%C3%A9>

3. <https://omniglot.com/writing/dioula.htm>

The current review aims to comprehensively analyze the specific features and functionalities of mobile solutions employed in existing health literacy initiatives within SSA. By critically evaluating the technological aspects of successful mHealth interventions, this study seeks to provide insights and recommendations to facilitate the effective utilization of mobile solutions, thereby empowering communities and promoting health literacy in the region [Ownby, 2019].

3.2 Methods

A systematic literature review was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, as shown in Figure 4.1. The review aimed to examine the role of mobile technology in improving health literacy in underserved rural areas in Africa. The main focus was to search for scientific articles, reports and projects dealing with mobile health (mHealth) and its impact on health care in Africa.

— Introduction and admission criteria

The guidelines of the PRISMA protocol were followed when selecting the literature. This ensured a systematic and careful approach to the review. Specific inclusion and exclusion criteria were defined that emphasised the relevance and quality of the studies. These criteria focused on interventions, particularly those targeting rural communities in Africa, and explicitly considered health literacy, access to healthcare or health outcomes. In addition, the selected studies had to have been published in English between 2011 and 2020.

— Search strategy.

Two well-known academic databases, SCOPUS and Google Scholar, were utilized extensively for their comprehensive coverage of academic publications. Moreover, grey literature research was conducted to identify reports associated with the mHealth project that fell outside the coverage of these databases. The search was conducted between July and August 2022 to capture relevant publications within the specified time frame. A strategic combination of keywords and terms such as "mobile health", "mHealth", "Africa", "health literacy", "rural", "underserved" and "mobile technology" was used to construct search queries. Boolean operators were used to tailor the search terms to the specific requirements of each database.

— Selection and evaluation of the studies.

After the initial search, retrieved datasets, including articles, reports and projects, were subjected to a rigorous screening process based on their titles and abstracts. Duplicates were removed, and the remaining datasets were thoroughly analysed based on their full texts. A review team critically appraised each article to determine whether it was consistent with the aims of the study and the inclusion criteria. Data relevant to the selected studies were systematically extracted, including publication details, study objectives, methodology, key findings, and the role of mobile technology in promoting health literacy.

— Synthesis and presentation of data.

The collected data was subsequently classified and examined to identify recurring patterns, trends, and characteristics associated with health interventions using mobile technology. A thorough evaluation was carried out to ensure the rigorous methodology and reliability of the selected studies. The evaluation criteria encompassed research methodology, sample size, data collection techniques, and the reliability of findings. Studies that exhibited better methodological rigor were given greater importance in the subsequent analysis. The results were compiled and presented in accordance with the comprehensive PRISMA-compliant review protocol, considering their distinct characteristics and implications.

3.3 Results

The systematic review of health initiatives in SSA revealed, as shown in the Table 4.1, that only 38 of 1,239 publications on health literacy and mobile technology were specifically focused on the use of mobile technology to improve health literacy in rural African regions. These initiatives targeted different areas of healthcare, including maternal and child health, sexual and reproductive health and chronic disease management. They utilised a range of technologies such as mobile websites, applications, SMS-based services and voice messaging to effectively disseminate health information and educational resources. Some programmes also integrated local languages to improve communication with target audiences. The review identified 38 initiatives in different countries, with a notable concentration in South Africa, Kenya and Nigeria, highlighting the comprehensive and innovative approaches to promoting health literacy and improving overall health outcomes in the region.

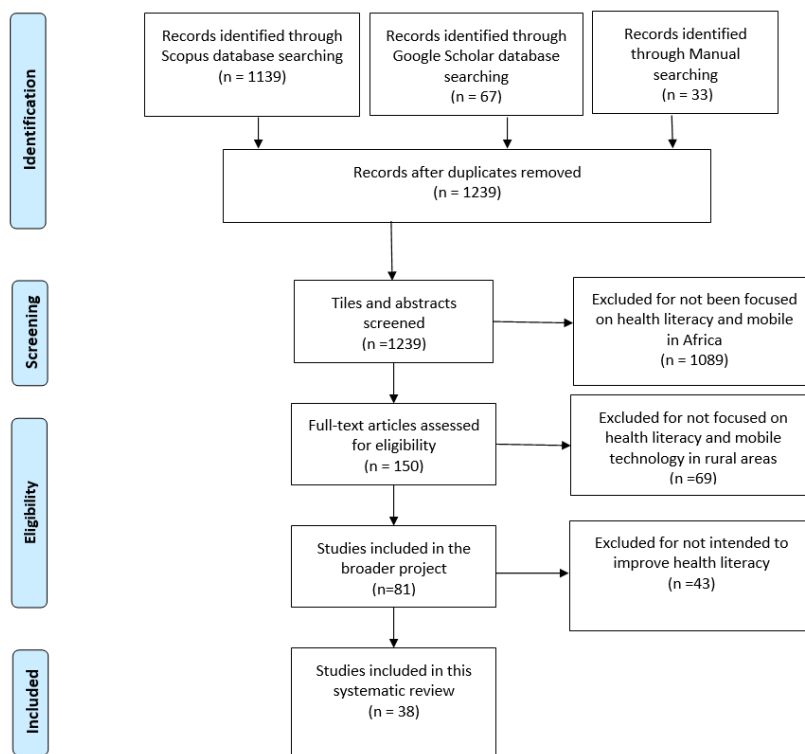


Figure 4.1 – Method used for the systematic literature review

Table 4.1 – Included studies and the technology used.

mHealth initiative	Country	Technology used
African Medical and Research Foundation (AMREF): distance learning for nurses	Kenya, Uganda	A mobile website designed for nurses enables access to information concerning communicable diseases like malaria and the rising prevalence of non-communicable diseases attributed to lifestyle changes. It is also utilized for peer-to-peer learning among nursing students. [Mukami, 2016].
eMOCHA: electronic mobile open-source comprehensive health application	Uganda	eMOCHA application provides multi-media courses and lectures (recorded in MP4 format), followed by quizzes to test users' knowledge of the information. It is also used to collect data and as a communication tool for health workers [Americas of the World Health Organization, 2013].
FrontlineSMS: Learn	Uganda	FrontlineSMS: Uses a free open source software, to support knowledge retention for trained health workers. JHPIEGO is also piloting the platform to prompt SMS based responses and quizzes on family planning modules after a training in Uganda [Health Market Innovations, 2005].
Health Education and Training in Africa (HEAT) Programme	Ethiopia	Uses online knowledge bank of learning resources that can be freely accessed by any individual, organizations training community health workers and global health institutions as well as exploring the use of mLearning for distribution [Tilahun, 2019].
Millennium Villages Project (MVP): continuous education for health workers	Ghana, Kenya, Uganda, Tanzania, Malawi	ChildCount + is a mobile technology solution enabling SMS-based mobile phone-based data collection and support on a RapidSMS platform [Källander, 2013a].

3. Review of mobile solutions used to enable Health Literacy in Africa: case study 1)

AED-SATELLIFE: Mobile Health Information System (MHIS)	South Africa	Provides health workers with locally relevant, reliable and accurate clinical information at the point of care through smartphones preloaded with a library of pertinent resources [Ladd, 2008].
HealthWiki	Tanzania	Allows users to browse eight free volumes of health information on a range of topics through mobile phones or computers [United States Agency, 2015].
EbolaTXT	Sierra Leone, Mali, Ghana, Uganda, Malawi	Using SMS for social mobilization and reporting on the Ebola outbreak [Energy, 2019].
iDEA	Nigeria	Providing health workers with mobile-based video instruction and reference materials [Toolkit, 2021].
OPPIAMOBILE	Ethiopia, Nigeria, Ghana	Platform which provides in mobile phones the complete national health extension worker (HEW) training materials [Michael B and Magnus Conteh and Siobhan Kelley, 2019].
U-Report	Nigeria, Liberia Sierra Leone	Uses SMS RapidPro to send messages to understand the needs of young people and providing them with information about Ebola [FundUNICEF, 2017].
ALERTE SMS E-SANTÉ	Ivory Coast	Aims to inform, raise awareness and advise on good health practices via SMS and USSD. Information, awareness-raising and advisory service in the field of health for the entire population.
VULA MOBILE	South Africa	Vula is an Android and iOS app that facilitates referrals between primary health workers and medical specialists and improve the care of patients in rural, remote and underserved areas ⁴ .
Service 3-2-1 ⁵	Congo Kinshasa Ghana Madagascar Malawi Nigeria Uganda	Provides access to important mobile health information (IVR/audio), in the local language.
Zero Mothers Die	Ghana, Mali, Gabon, Nigeria	Using mobile technology to increase access of pregnancy information and emergency care [Die, 2017].
MomConnect	South Africa	Through this platform, every pregnant woman in South Africa can register to receive free, informative, stage-based messaging via SMS or WhatsApp for her pregnancy up to the second year of her baby's life [Kabongo, 2019].
MY Virtual Planning	Democratic Republic of Congo	ePrevents unwanted pregnancies by educating young people about sexuality, and by facilitating access and effective use of modern contraceptives thanks to digital technology [OBSERVATORY, 2017].
YAAY.SN ⁶	Senegal	It is educational and offers everyday decision-making tools for mothers, in key subjects like healthcare, education, and careers/entrepreneurship [OBSERVATORY, 2014].
m-NUTRITION	Malawi, Zambia	Contributes in preventing and reducing chronic malnutrition, through access to nutrition information via mobile technology [OBSERVATORY, 2023].

4. <https://www.odess.io/en/initiative/vula-mobile/>

5. <https://viamo.io/fr/>

6. YAAY=Mom in WOLOF, main language in Senegal)

TBIBCOM	Morocco	Offers a support service for patients suffering from chronic diseases via a "patient" platform, available online and on mobile phones, containing a therapeutic education module and a tele-monitoring module. It offers educational videos (short, in Arabic dialects, easy to understand) as well as educational games to inform and ensure the patient adheres to their treatment, then to consolidate and verify the knowledge gained [OBSERVATORY, 2019b].
Apprendre A Vivre ⁷	Senegal	Giving access to accurate information regarding sexual and reproductive health and right [Hudig, 2012].
THE NUTRICARTES application game on android phone	Madagascar, Burkina Faso, Chad, Niger	Gives nutritional education to families for children under the age of 5 years old is given via a game which is made of photo cards that represent foods found on the market and a mat with 4 colours: Red for construction foods (proteins), Yellow for Energy foods (carbohydrates, lipids), Green for Protection foods (vitamins, micro-nutrients) and Blue for water [OBSERVATORY, 2023].
ASCA BENIN	Benin	Uses SMS to Send monthly messages to patients suffering from mental illnesses under treatment to remind them of their day of visit to the health centres [OBSERVATORY, 2019a].
Google SMS – Health Tips	Uganda	SMS-based service that allows users to access information on healthcare [Swati, 2009].
MTN Kick Out Malaria	South Africa	SMS based quiz which intent to educate the public about malaria [Malaria-Free Future, 2010].
Freedom HIV/AIDS	Kenya	Mobile based games designed to create HIV/AIDS awareness.
Project Masiluleke	South Africa	Uses SMS messages to provide referral to the National AIDS Helpline.
Text to Change	Kenya, Uganda	General HIV/AIDS quiz using SMS to create HIV/AIDS and public health awareness [Chib, 2012].
Young Africa Live	South Africa	Mobile entertainment portal designed to engage youth on topics related to sexual health [GSMA, 2009].
M4RH	Kenya, Tanzania	Automated SMS based system that provides access to family planning information [LEngle, 2013].
MoTeCH Mobile Midwife	Ghana	Java-based information service that delivers time-specific voice or text messages to pregnant mothers and their partners and families before and after childbirth [LeFevre, 2017].
Allo Laafia ⁸	Burkina Faso	Use SMS and voice messages sending personalized advice on various health topics.
Polly	Guinea	Uses voice messages to send information related to Ebola epidemic [Wolfe, 2015].
SMS for education and promotion	Low income countries	Mobile health literacy to improve health outcomes in low-middle income countries Low income Book [Vaz, 2017].
SMS for education and	Liberia	Collection Using SMS Text Messaging in Areas of Low Network Coverage from Low-Literacy Provider [Lori, 2012].
WeChat	Niger	Uses WeChat official (social medial) accounts to improve malaria health literacy among Chinese expatriates in Niger: an intervention study [Li, 2016a].

7. Learning to live

8. <https://www.afd.fr/en/actualites/text-messages-raise-awareness-about-health-and-hygiene>

SMS for education	South Africa	SMS messaging systems to improve tuberculosis treatment [Adam Wagstaff, 2019].
SMS for education	South Africa	SMS messaging systems to improve hypertension knowledge for deaf South Africans [Haricharan, 2017].

3.4 Findings

Integration of local language in mHealth initiatives:

The integration of local languages into mHealth initiatives is crucial to effectively address the challenges of health literacy in rural Africa. Projects such as HealthWiki, Viamo's 3-2-1 service, ALERTE SMS E-SANTÉ, YAAY.SN and the NUTRICARTES application are examples of this approach by providing health information, counselling services and educational content in easily accessible local languages via mobile devices. Community participation in content creation is critical to building trust and increasing the effectiveness of health interventions. Collaboration between different stakeholders, including governments, health institutions, universities, mobile operators and non-governmental organisations, is essential for the successful implementation of mHealth projects in rural Africa.

Voice enabled user interface in mHealth solution: Advances in voice interfaces further improve accessibility and usability, especially for people with low literacy skills. Initiatives such as TBIBCOM's telemonitoring module and Polly's voice messages on the Ebola epidemic provide information in spoken form to overcome literacy barriers. These voice-based features aim to present information in a format that is understandable and accessible to a wider audience.

Viamo's 3-2-1 service was developed specifically for evaluation in low literacy populations and demonstrates a commitment to evaluating the impact of interventions on health literacy. However, further research and development is needed to fully realise the potential of language technology in addressing health literacy issues in sub-Saharan Africa.

The issue of digital inclusion is high on the agenda of nations as they endeavour to find ways for citizens to gain access to ICTs. However, despite these efforts, many people on the continent remain either completely excluded or limited by various factors. Many people in Africa are either illiterate or have low literacy skills. Those who can read and write may only be able to do so in their local language. Digital inclusion is a major challenge. While cost, affordability, availability and quality of services remain major barriers to digital inclusion, literacy could be a key issue for digital inclusion across the continent. Most reports on ICT access and use focus little on education and skills.

The findings in this case study 1 highlight the urgent need for mHealth initiatives to prioritise local language integration and voice user interface for a more comprehensive effort to address the challenge of digital inclusion by considering literacy as a key enabler of ICT access and use across Africa.

3.5 limitations

While the study sheds light on various mobile health initiatives in SSA, it also has some limitations that need to be addressed. The selection of initiatives could lead to bias and potentially overlook relevant programmes that were not captured in the SCOPUS and Google Scholar database searches. Furthermore, limiting the search to English-language publications between 2011 and 2020 could lead to valuable information published in other languages or before the specified period being missed. Furthermore, the study lacks an in-depth analysis of the implementation challenges, long-term sustainability and actual effectiveness of these initiatives. This limitation hinders a comprehensive understanding of the actual impact of the initiatives and their potential to address the challenges of health literacy in rural African communities. Aspects of ethics and cultural sensitivity in the implementation of these interventions are also underrepresented, emphasising the need for more thorough engagement with local communities and cultural experts. To address these limitations, a broader search strategy is needed that includes sources in different languages, conducts qualitative follow-up assessments, and encourages more in-depth analyses of implementation challenges, sustainability, and cultural considerations to improve the scope and validity of the study.

4 Literature Review of Serious Mobile Games Used to Improve Health Literacy in Rural Sub-Saharan Africa. (Study case 2)

4.1 Context

The African gaming industry has experienced significant growth due to the increasing availability of affordable mobile phones and the growing number of mobile phone subscribers [Menabde, 2017]. This has led to increasing emphasis on the development and implementation of mobile serious games aimed at promoting healthy behaviours in rural communities. This study critically examines the use of mobile serious games in health education, with a particular focus on promoting health literacy in rural Africa [Bastos de Morais, 2017]. By identifying the specific challenges in designing games for rural African communities, the study aims to demonstrate the potential of compelling mobile games in promoting behaviour change in these underserved populations.

The widespread use of mobile technologies and the increasing popularity of games among diverse populations have made serious games an effective tool for delivering compelling content while providing an enjoyable user experience [Hammady, 2022; Peng, 2009]. These games subtly motivate behaviour change by engaging users in an entertaining and interactive format. The research findings are expected to provide valuable insights to researchers, designers and developers of digital games, especially to understand the challenges faced by users in rural African communities. In addition, the study highlights the importance of tailoring design solutions that address the particular constraints and preferences of the target audience in rural Africa, where resource constraints and infrastructural barriers are significant hurdles. In considering these recommendations, digital serious games can be optimised to meet the specific needs of users in resource-limited regions. This study contributes to ongoing efforts to use technology to promote health education and support positive behaviour change in underserved communities.

4.2 Methods

The inclusion criteria for our study were formulated based on the question: "What mobile games are available in Africa to improve health literacy?" Health literacy, defined as "the ability to access, understand, evaluate, and apply health information" [Kickbusch, 2013], guided our search for mobile applications that facilitate these aspects of health information processing to promote healthier behaviours and outcome [Zhang, 2021]. These interventions needed to incorporate mobile technologies such as smartphones, tablets or smartwatches and target positive behaviour change and lifestyle improvements to achieve better health outcomes. Our study adhered to the PRISMA protocol [Liberati, 2009]. We considered a wide range of studies, including articles and publications from 2011 to July 2021, written in English, to identify mobile serious game interventions from the last decade in Africa. In selecting this time period (2011–2021), we aimed to capture the surge in access to mobile phones in sub-Saharan Africa during this period [Kharono, 2022].

— Selection of the database:

Our literature search utilised PubMed, Scopus, Google Scholar and manual searches using specific search terms.

— Keyword search:

We conducted our search on 25 July 2021 using Boolean operators ('AND', 'OR'). The search terms targeted titles, abstracts, and keywords of articles related to the role of mobile games in improving health literacy in Africa. The search query included combinations such as 'mobile health*' AND 'serious game*' AND 'education and awareness' AND 'Africa'.

— Selection of studies:

We restricted our selection to English-language publications and focussed on studies published between 2011 and 2021 to take into account the rapid development of mobile technologies. No restrictions were placed on the authors.

— Data extraction:

We exported the relevant data (title, abstract, keywords, author, publication date, country of origin) to a CSV file. This was followed by a full-text check according to specific criteria:

For inclusion

- studies dealing with mobile serious games, education and awareness.
- studies dealing with public health issues in Africa.
- studies addressing health literacy and mobile serious games in rural areas.

Excluded studies that did not fulfil these criteria.

4. Literature Review of Serious Mobile Games Used to Improve Health Literacy in Rural Sub-Saharan Africa. (Study case 2)

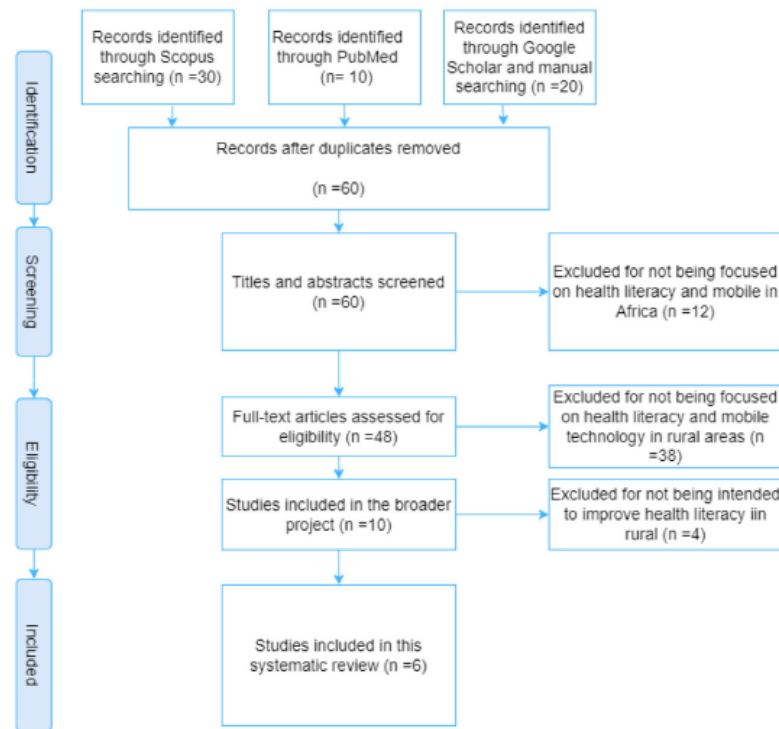


Figure 4.2 – Flow diagram for the study selection process

4.3 Results

The selection of studies, as shown in Figure 4.2, initially identified 30 publications from Scopus, 10 from PubMed and 20 from Google Scholar. After eliminating duplicate entries, 48 articles were subjected to a thorough review, excluding 12 articles during the title and abstract review. Subsequently, 10 articles underwent a comprehensive full-text screening, with only 6 articles meeting the criteria related to mobile serious games, education and health information in rural Africa.

According to the data in Table 4.2, the interventions analysed in the study were implemented in different African countries, including Nigeria (2), Kenya (2), Swaziland (1) and Ghana (1). Among these interventions, two serious games, Tumaini and SwaziYolo, were evaluated in randomised controlled trials. The targeted behaviour change initiatives focused mainly on HIV prevention among young people (3), malaria prevention (2) and Ebola prevention (1). It is worth noting that all digital solutions were developed exclusively in English and specifically supported Android devices, which require internet access to operate.

Table 4.2 – Included games and the technology used.

Game name	Country	Technology used
SwaziYolo [Lukhele, 2016]	Swaziland	SwaziYolo, a smartphone game, is an interactive, educational story game that puts the player in the role of a young adult looking for love in Swaziland, making important choices about relationships and sexual health. The game targets young adults (18-29 years). Characteristics Language of the game: English. The game is a 49MB Android operating system. Internet is required.

My Jorley ⁹	Ghana	My Jorley is a serious game for healthy sexual behaviour, in Ghana and beyond. The game targets young people. Characteristics Language of the game: English. Android system. Internet is required
ChopUp Game (Ebola Strike Force) ¹⁰	Nigeria	Ebola Strike Force represents a paradigm shift in mobile gaming, empowering users not only to experience thrilling gameplay but also to learn about the Ebola virus in an interactive and immersive manner. The game targets all ages. Characteristics Language of the game: English. Android system. Internet is required
Mosquito Smasher ¹¹	Nigeria	Mosquito Smasher Game is a FUN game where you need to smash mosquitoes as much as you can. Every successful tap of a mosquito counts a point . The game targets all ages. Characteristics Language of the game: English. Android system. Internet is required
Mosquito Hood ¹²	Kenya	Mosquito Hood is a fast-paced 2D casual game that aims to save Africa from the mosquito-borne disease Malaria by spreading real nets across the continent. Players earn points for advancing through sprite levels and for completing the game's objective. The game is meant for all ages. Characteristics Language of the game: English. Android system. Internet is required
Tumaini [Winskell, 2019]	Kenya	Tumaini is a narrative-based smartphone game designed to help prevent HIV among young Africans . The game targets 11 to 14 years. Characteristics Language of the game: English. Internet is required. Android system

4.4 Findings

The main findings in this study case 2 suggests that mobile serious games have the potential to improve access to health information and lead to positive behaviour change in both young people (11–14 years) and adults (18–29 years) [Lukhele, 2016; Sabben, 2019]. A randomised controlled trial using the game SwaziYolo found that young adults (18-29 years) had increased intentions to reduce their sexual partnerships and were more motivated to know their partner's HIV status (-24). Similarly, evaluation of the Tumaini Game showed significant improvement in sexual health knowledge and self-efficacy among 11–14-year-olds [Sabben, 2019]. In malaria prevention campaigns, serious games such as Mosquito Bonnet were effective in motivating more than 1,400 households in remote areas of rural Kenya to adopt preventive measures such as the use of insecticide-treated bednets [Ouedraogo, 2022a].

However, the implementation of sustainable mobile health interventions faces significant challenges due to limited resources in rural areas. For example, the cost of accessing ChopUp Game (Ebola Strike Force) in Nigeria was a financial barrier. in

9. https://www.myjorley.com/wp-content/uploads/2018/11/Theory-of-Change-My-Jorley_2.pdf

10. <https://www.chopup.me/app/ebola-strike-force/>

11. <https://apkspc.com/Game/free.mosquito.smasher.games/>

12. <https://killscreen.com/previosly/articles/smartphone-game-helping-fight-against-malaria-kenya/>

5. Assessing the effectiveness of using a phone and local language-based Interactive Voice Response (IVR) service for improving malaria literacy: case study 3

2015, users had to pay N30 (\$0.12) weekly¹³, which was unaffordable for the majority of the rural population living below the poverty line [Arayavechkit, 2021]. In addition, limited access to electricity - only 24.6% of the Nigerian population has reliable access - makes it difficult to roll out mobile-based interventions [Ouedraogo, 2022a]. Despite the increasing penetration of mobile technology in Africa, internet connectivity in rural areas remains inadequate.

In addition, cultural context plays a crucial role in the acceptance of technology-based interventions, as seen with the introduction of My Jorley in Ghana, where games were perceived as unserious in some cultural contexts [Ouedraogo, 2022a]. In our study, all included games were developed in English and required an internet connection, which is often not available in rural areas where internet access is sporadic [Sabben, 2019]. Given the high illiteracy rate among people over 15 in SSA, the development of technologies with graphical user interfaces (GUI) that require reading and writing could further complicate accessibility for users with low literacy skills [Shiundu, 2018]. These multi-faceted challenges underscore the need for culturally sensitive, linguistically appropriate and accessible design considerations when developing mobile serious games for rural African communities.

4.5 Limitations

The study, which examines mobile serious games to promote health literacy in SSA, is subject to several limitations that affect the depth and breadth of the analysis. First and foremost, the limited number of articles meeting the inclusion criteria suggests that valuable initiatives not included in the selected databases may have been overlooked. This limitation could lead to an incomplete representation of available interventions and limit the scope of the study. In addition, the preponderance of English language publications among the selected studies introduces a linguistic bias, potentially excluding key findings from local languages and non-English resources and limiting the diversity and inclusiveness of findings in different linguistic settings in sub-Saharan Africa.

Furthermore, the temporal focus of the study from 2011 to 2021 may overlook earlier pioneering initiatives or more recent advances in mobile serious games for health literacy. This limited timeframe could undermine the timeliness and relevance of the study in a dynamic field characterised by frequent technological advances. To address these limitations, the search criteria could be expanded beyond standard databases, multilingual resources considered, the time frame extended, and in-depth research on cultural and technological adaptations conducted to increase the inclusivity and relevance of the study in effectively addressing health literacy challenges in rural sub-Saharan Africa.

5 Assessing the effectiveness of using a phone and local language-based Interactive Voice Response (IVR) service for improving malaria literacy: case study 3

5.1 Context

Malaria remains a major health challenge in underserved regions, particularly among Internally Displaced People (IDP) in Burkina Faso. Despite ongoing efforts such as the distribution of insecticide-treated nets, the disease persists due to limited access to health services and poor living conditions. In 2021, Burkina Faso hosted more than 1.5 million IDP, exacerbating the scarcity of health services for these mobile populations. Health education is critical for disease prevention, but there is a significant knowledge gap among vulnerable populations. Health literacy, which depends on individual skills and healthcare resources, plays a critical role in addressing this gap. To improve health literacy and combat malaria, innovative information and communication technologies (ICTs) such as mobile phones are being explored. This study focuses on evaluating the effectiveness of Viamo's 3-2-1 IVR service, an innovative, multilingual, mobile phone-based IVR system. Viamo's 3-2-1¹⁴ service delivers health information in local languages through IVR and makes it accessible to people with different levels of education. The study aims to find out how this technology can provide underserved communities such as IDP in Burkina Faso with knowledge and effective prevention practices related to malaria. By harnessing the power of Viamo's 3-2-1 IVR service, the study aims to bridge the information gap and help reduce malaria in these vulnerable populations. This study is a critical step in understanding the potential of ICTs such as Viamo's 3-2-1 IVR service in improving health care and reducing disease transmission in resource-limited and underserved communities.

13. <https://techcabal.com/2015/09/04/chopups-new-business-model-subscription-based-gaming/>

14. <https://viamo.io/>

5.2 The 3-2-1 Service: the Viamo platform

The 3-2-1 service developed by VIAMO is a mobile service that provides users with information on various development topics through an IVR system. By early 2022, this service was available in 20 countries and reached more than 130 million mobile subscribers. Its main function is to allow users to interact with a host system operated by a company via a toll-free number and a telephone keypad. The service is notable for its multilingualism. It provides information in six languages, including French, the official language of Burkina Faso, and five local languages spoken in the country.

Upon dialing the toll-free numbers 3, 2, and 1, a welcome message is played and the caller is given the choice to select their preferred language by pressing the corresponding number. The system is designed to be intuitive, allowing callers ample time to make their selections and providing clear instructions for navigation. Users have the option to terminate the service at any point by pressing the asterisk symbol (*). The 3-2-1 service is implemented through a collaboration with Orange Burkina Faso, a mobile operator, which likely enhances its extensive adoption.

In 2021, the service recorded remarkable usage figures, with more than 4.5 million calls from 350,000 subscribers. These users listened to a total of 7.2 million key messages, underlining the impact of the service in providing important information to the community and its popularity among mobile subscribers in Burkina Faso. Overall, the 3-2-1 service's user-friendly interface and multilingual support make it a valuable tool for disseminating development-related information, especially in regions where mobile phones are widely used.

5.3 Methods

The main objective of the study was to assess the effectiveness of the multilingual mobile IVR service, particularly the 3-2-1 service, in improving malaria health literacy among IDPs in Pazani camp, Burkina Faso. The Pazani IDP Camp is situated in an unplanned area of Arrondissement 9, about 15 km away from Ouagadougou, Burkina Faso. It serves as a residence for many internally displaced persons who have fled due to insecurity.

5.3.1 Justification of Sample Size and Power Analysis

When determining the sample size for this study using the OpenEpi¹⁵, we adhered to specified parameters, including a significance level of 95% and a power of 80%. The sample size ratio between the unexposed (French language) and exposed groups (Moré language) was 1, with the percentage of unexposed malaria knowledge being 50% and the percentage of exposed malaria knowledge being 80%. With an odds ratio of 4 and a risk-prevalence ratio of 1.6, the calculated risk-prevalence difference was 30. Additionally, we incorporated data from a separate study in Niger, which provided baseline health literacy rates of 58.29%, 62%, 54%, and 34% for skills, knowledge, practice, and attitude, respectively [Li, 2016a]. Using this information, our initial calculations suggested a requirement of 80 participants. However, we ultimately included 97 participants in our study to ensure adequate representativeness.

5.3.2 Recruitment Process and Ethical Approval

The study enrolled 97 internally displaced persons (IDPs) from the Pazani Camp in Burkina Faso. Recruitment was conducted randomly to ensure fairness and representation. Ethical approval was granted by the Nazi Boni University Doctoral School Ethics Committee, in adherence to the Declaration of Helsinki. Verbal consent was obtained from participants, with parental or guardian consent sought for those under 18. Participants' identities remained confidential, and only identification numbers were used. Given the cultural emphasis on oral agreements [Tindana, 2006], oral consent was preferred due to participants' low literacy levels. As a gesture of appreciation, each participant received a \$5 meal at the study's conclusion.

5.3.3 Exclusion of Non-participants and Sample Representativeness

Certain IDPs were excluded from participation for various reasons, including non-membership in the Pazani Camp, inability to commit to the entire study duration, refusal, or reluctance to use the 3-2-1 Service. Initially, 100 participants were recruited, but ultimately, 97 participants who owned a feature phone with an Orange Burkina SIM card were integrated. Three individuals, comprising two women and one man, did not participate in the study. Their reasons for non-participation could vary and might include factors such as not being from the Pazani Camp, inability to commit to the entire study period, refusal, or reluctance to use the 3-2-1 Service.

15. <https://www.openepi.com/SampleSize/SSCohort.htm>

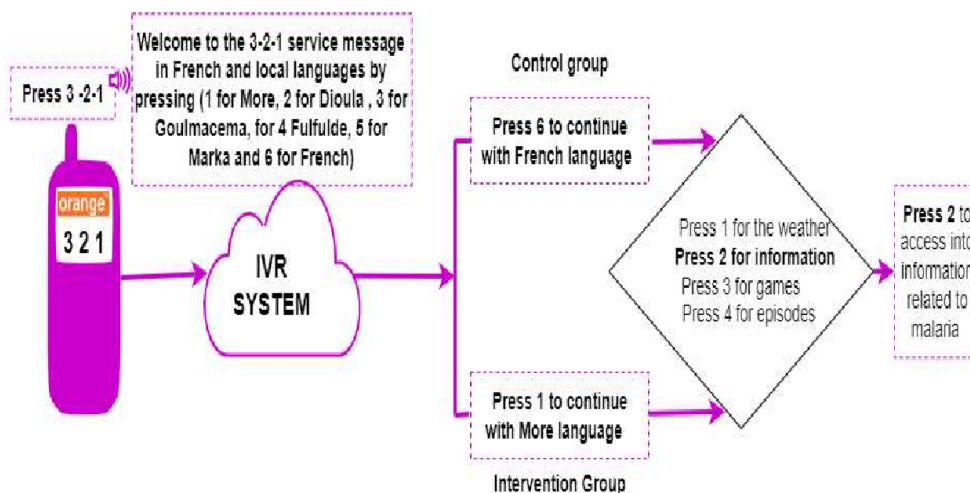


Figure 4.3 – 3-2-1 IVR service usability procedure in the study.

5.3.4 Creation of Intervention and Control Groups

The phone numbers of all 97 participants were randomly written on paper (without names) and then randomly assigned to either the intervention or control group. The first 49 numbers were designated for the intervention group, utilizing the Moré language version, while the remaining 48 numbers were allocated to the control group, utilizing the French language version. This method was employed to prevent bias in group assignment.

5.3.5 Selection Criteria and Randomization Process

Ownership of a feature phone with an Orange Burkina SIM card was a selection criterion considered during the randomization process. However, potential bias may exist if individuals with access to such phones differ systematically from those without within the Pazani Camp. Additional details on the randomization process and its implementation would enhance transparency and validity.

The Viamo 3-2-1 service, facilitated by Orange's telecommunication network, benefits from Orange Burkina Faso S.A.'s significant market dominance, which accounted for 44.23% of active SIM cards in 2021 [ARCEP, 2023]. This partnership provides free access to the service, potentially benefiting vulnerable populations. With Orange's extensive coverage and affordable SIM card costs (1 USD) [ARCEP, 2023], the service reaches a diverse demographic, promoting equitable access to health information and education, particularly in rural or underserved areas. Including Orange SIM card ownership as a selection criterion does not introduce bias, as it ensures accessibility for economically vulnerable individuals.

5.3.6 Statistical Analysis

A thorough analysis was conducted using IBM SPSS Statistics software. Descriptive statistical analysis was performed on demographic data, while chi-square tests were utilized to evaluate statistical differences between groups, with $p < 0.05$ indicating significance.

The usability procedure of the 3-2-1 service during the study is shown in Figure 4.3 for both the control and intervention groups.

The research protocol implemented in the study is shown in detail in Figure 4.4. Specifically, the procedure included the initial administration of health literacy questionnaires to participants before and after the intervention (see Appendix 2 Table 5). Detailed instructions and information sheets were provided to participants to guide them in the effective use of the 3-2-1 service. Participants were then instructed to use the 3-2-1 service, with the intervention group using the Moré language version and the control group using the French language version. After a two-week intervention phase, the study reassessed the level of malaria health literacy using the same evaluation tool.

In summary, our research employed an experimental approach to evaluate the effectiveness of the 3-2-1 service in improving malaria health literacy among IDP residing in Pazani camp. Data collection encompassed health literacy assessments conducted

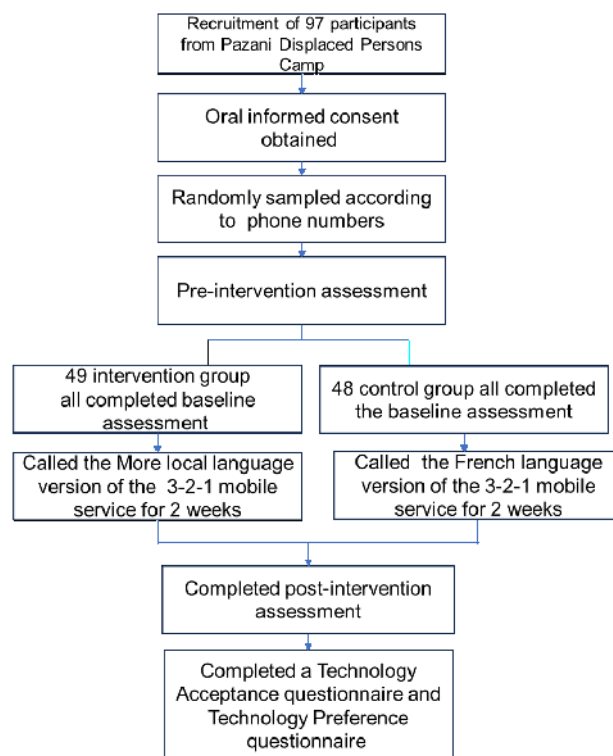


Figure 4.4 – Study protocol flowchart.

before and after the intervention, with a particular focus on identifying factors impacting service adoption and understanding its impact on health literacy levels.

Table 4.3 – Sociodemographic characteristics of displaced women in Pazani camp in Burkina Faso: intervention group (Users of the Moré language version of 3-2-1 IVR Service) versus the control group (users of the French language version of 3-2-1 IVR Service)

Contents	Groups	Baseline total(n=97)		Control group(n=48)		Intervention group (n=49)		χ^2	p
		n	%	n	%	n	%		
Gender	Female	79	81,4	39	81.3	40	81.6	22.556	0.110
	Male	18	18,6	9	18.8	9	18.4		
Age (years)	18-<	6	6.2	15	6.3	3	6.1	8.796	0.456
	18-<24	30	30.9	23	31.3	15	30.6		
	25-<50	47	48.5	7	47.9	24	49.0		
	<50+	14	14.4	3	14,6	7	14.3		
Education	Uneducated	65	67.0	32	66.7	33	67.3	5.860	0.210
	Primary school	16	16,5	8	16.7	8	16.3		
	High school	16	16,5	8	16.7	8	16.3		
Income	40 000 CFA <	87	89.7	43	89.6	44	89.8	0.649	0.957
	>= 40 000 CFA - <100 000 CFA	4	4.1	2	4.2	2	4.1		
	<100 000 CFA	6	6.2	3	6.3	3	6.1		

5.4 Results

The results related to the socio-demographics of the participants are illustrated in Table 4.3. A total of 97 IDP participated in the study, with the majority (81.4%) being women and the remaining 18.6% being men. The age of the participants varied: 30.9% were between 18 and 24 years old, 48.5% between 25 and 50 years old, 14.4% over 50 years old and 6.2% under 18

5. Assessing the effectiveness of using a phone and local language-based Interactive Voice Response (IVR) service for improving malaria literacy: case study 3

Table 4.4 – Comparison of accuracy rate of malaria-related health literacy between the two groups, before and after intervention

Questions	Before Intervention				After Intervention			
	Intervention(n=49)		Control(n=48)		Intervention(n=49)		Control(n=48)	
	n	%	n	%	n	%	n	%
Knowledge		52.60		51.84		82.98		67.82
Malaria causes serious health consequences	49	100	48	100	49	100	48	100
Cause of malaria: Diet	7	14.28	9	18.75	25	51.02	13	27.08
Cause of malaria: Sun	9	18.36	12	25	45	91.83	24	50
Cause of malaria: Dirty environment	30	61.22	27	56.25	49	100	40	83.33
Cause of malaria: Lack of personal hygiene	25	51.02	23	47.91	47	95.91	38	79.16
Transmission of malaria: Female mosquito bites	48	97.95	46	95.83	48	97.95	47	97.91
Transmission of malaria: Bad spell or spirit. supernatural or mystical cause	2	4.08	4	8.33	30	61.22	18	37.5
Transmission of malaria: Work Fatigue	15	30.61	14	29.16	25	51.02	19	39.58
Signs or symptoms of malaria: fever. headache. diarrhoea	47	95.91	41	85.41	48	97.95	46	95.83
Attitude		70.74		74.30		92.51		88.88
To prevent malaria. sleep under a mosquito net	49	100	48	100	49	100	48	100
Pregnant women should wait 2 days before visiting hospital	40	81.63	42	87.5	47	95.91	45	93.75
Only severe cases of malaria should be treated in hospital	15	30.61	17	35.41	40	81.63	35	72.91
Practice		25.16		24.30		60.54		38.88
Treatment of malaria is free for children under 5 in Burkina Faso	20	40.81	18	37.5	42	85.71	30	62.5
Malaria prevention activities are only carried out during the raining season	5	10.2	7	14.58	25	51.02	14	29.16
The best practice for malaria diagnosis and treatment is self-medication	12	24.48	10	20.83	22	44.89	12	25

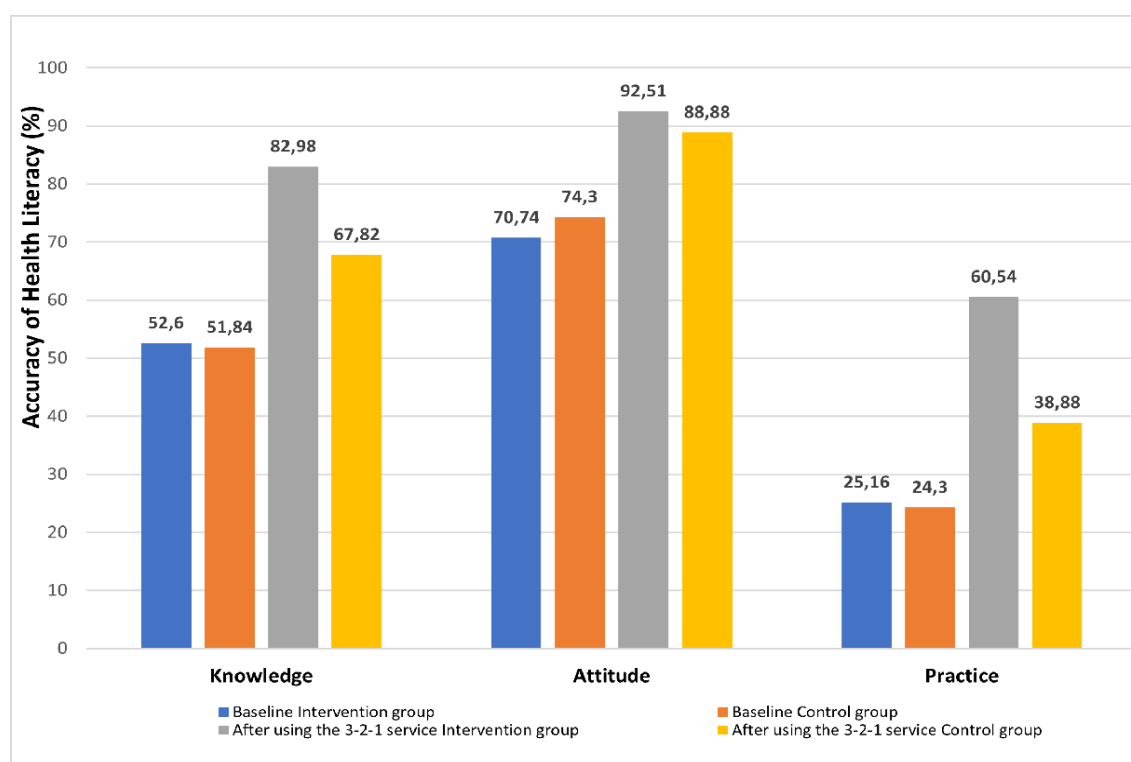


Figure 4.5 – Comparisons of changes in malaria-related health literacy accuracy rate between intervention and control groups

years old. In terms of education, 67% of the participants were uneducated, while 33% had a primary or high school diploma. In terms of socio-economic status, 89.7% had a monthly income below the poverty line, while only 10.3% had an income above this threshold. There were no significant demographic differences between the health education intervention group (users of the Moré language version of the 3-2-1 service) and the control group (users of the French language version).

5.5 Effectiveness of the Moré language version of the IVR for health education

At baseline, the level of knowledge about malaria was 52.6% in the intervention group and 51.84% in the control group. The attitude score was 70.74% in the intervention group and 74.3% in the control group. The practice score was lowest at 25.16% in the intervention group and 24.3% in the control group. While baseline knowledge and attitude scores were relatively high, indicating some level of understanding, the study showed that participants had misconceptions about malaria. A significant percentage of participants in both groups attributed malaria to factors such as diet, sun exposure, mystical or supernatural causes and work fatigue.

As shown in Table 4.4 after using the 3-2-1 service, participants in both the intervention group (in the Moré language) and the control group (in the French language) showed improved health literacy about malaria, with the intervention group showing significantly greater improvements in all aspects - Knowledge, Attitude, Practice and general health literacy ($p < 0.01$). Post-intervention hit rates for Knowledge and Attitude were over 60%, while the practice aspect reached 38.88%. The Moré language group showed the greatest improvements: 30.38% for knowledge, 21.77% for attitude and 35.38% for practice. In contrast, users of the French version showed relatively lower improvements (15.98% in knowledge, 14.58% in attitude and 14.5% in practice). A comparison of changes in malaria health literacy between the two groups showed that users of the Moré language showed greater improvements.

When examining the changes between the local language (Moré) and French language groups after the intervention in Figure 4.5, it was found that Moré language users showed significantly greater improvements in all aspects of health literacy related to malaria. In particular, the Moré language group showed a significant increase of 30.38% in knowledge, 21.77% in attitude and 35.38% in practice. In contrast, the French-speaking group showed comparatively smaller improvements: 15.98% more knowledge, 14.58% more attitude and 14.5% more practical experience. These results emphasise the importance of incorporating local languages to support health literacy initiatives and improve health outcomes, particularly in regions with diverse linguistic populations.

5.6 Findings

The study conducted in Pazani camp in Burkina Faso focused on assessing the malaria health literacy of IDP's and evaluating the effectiveness of a multilingual Interactive Voice Response (IVR) service for health education [Polonsky, 2013]. IDP living in crowded and suboptimal conditions are at higher risk of infectious diseases such as malaria, so health literacy is critical for making appropriate health decisions [Jacobs, 2016].

The study found that IDP overall health literacy about malaria was low, with less than 50% demonstrating adequate Knowledge, Attitudes and Practices (KAP) about malaria prevention. In particular, malaria practice scores were exceptionally low at less than 35%. However, knowledge about mosquito nets and the link between mosquitoes and malaria was relatively high [Li, 2016b].

To address these issues, a multilingual health education IVR service was introduced, allowing IDPs to access information in their preferred language [Kraft, 2012]. Both the intervention group (local language) and the control group (French language) showed improvements in malaria health literacy. However, the intervention group showed significantly greater improvements. Malaria knowledge scores increased by 30.33%, attitude scores increased by 21.77% and practice scores increased by 35.38%. In comparison, the control group showed relatively smaller improvements (Moré local language)[A Moran, 2013].

These findings highlight the importance of evidence-based malaria prevention strategies and the need to address misconceptions. Misconceptions about the causes and transmission of malaria, such as attributing malaria to diet, sun exposure, supernatural causes or work fatigue, were common among participants [Finlay, 2017].

In summary, this study highlights the urgency of targeted health education initiatives, particularly among vulnerable populations. It also shows that IVR services in local languages have the potential to significantly improve health literacy, especially in underserved communities in sub-Saharan Africa [ODonovan, 2015]. This approach can help reduce misinformation and improve malaria knowledge and practises [Al Sayah, 2013].

5.7 Limitations

The evaluation of Viamo's 3-2-1 IVR service to improve malaria health literacy among internally displaced people in Burkina Faso provided valuable insights but had certain limitations. The study focussed on 97 participants, mainly women, and highlighted that knowledge, attitudes and practises regarding malaria were initially low among this vulnerable group. While the introduction of the IVR service in local languages significantly improved health literacy, particularly among Moré users, the limitations of the study prevented a comprehensive understanding. The scope of the study, which focused on one particular camp and a relatively small sample, may limit its applicability to other IDPs. In addition, the study's focus on short-term improvements in health literacy without examining the lasting impact of the IVR service on behaviour change or actual disease prevention limits the depth of conclusions. To deepen future findings, supplementing quantitative data with qualitative perspectives or feedback from the community could enrich the contextual understanding needed to more holistically improve health literacy among IDPs in Burkina Faso.

6 Conclusion

In summary, the three case studies presented in this chapter shed light on the potential of mobile-based local speech and language technology in addressing health challenges in underserved communities, particularly in Africa. The findings highlight the critical role of technology-enabled interventions in improving health literacy, bridging information gaps and ultimately improving health outcomes.

Case study 1 and 2 highlights the transformative power of mobile technology in addressing health inequities in rural African settings. It demonstrates the importance of providing health information in local languages to make it culturally appropriate and linguistically accessible. By focusing on user-friendly interfaces and collaboration between stakeholders, mobile health initiatives can empower communities with valuable knowledge and ultimately contribute to better health in underserved regions.

Case study 3 looks at the effectiveness of a telephone and local language-based IVR in combating malaria in Burkina Faso. The study shows how technologies such as Viamo's 3-2-1 IVR service can bridge the information gap and improve disease prevention in vulnerable populations. The user-friendliness and multilingualism of the 3-2-1 service highlight its potential to improve accessibility and understanding of health care.

Taken together, these case studies provide compelling evidence of the transformative impact of mobile health interventions. By integrating local languages, cultural sensitivity and user-centred design, technology-enabled solutions can empower communities, improve health literacy and contribute to better health outcomes in underserved areas. These findings underscore the importance of continued efforts to use technology to benefit marginalised populations and ensure equitable access to critical health information and services.

In this chapter, we assessed the contribution of mobile-based local language and voice technology in improving health literacy among underserved communities. We now proceed in Chapter 5 by designing a prototype of a mobile-based solution for health information targeting the low-literate.

Chapter 5

Designing a mobile-based solution for health information targeting low-literate

The contributions to this chapter have been discussed in the following publications:

M.Some, **I. Ouedraogo**, R. Benedikter, R. Yameogo, G. Ateazing, I. Traoré, G. Diallo. "Interactive Voice Response Service to Improve High School Students Covid-19 Literacy in Burkina Faso: A Usability Study". *Advances in Informatics, Management and Technology in Healthcare*,.. DOI: <https://doi.org/10.3233/shti220763>

M.Some, **I. Ouedraogo**,R. Benedikter, R. Yameogo, G. Ateazing, I. Traoré, G. Diallo. "Improving Covid-19 vaccine literacy among undergraduate students in Burkina Faso". *IEEE 10th International Conference on Healthcare Informatics*. DOI: <http://dx.doi.org/10.1109/ICHI54592.2022.00096>

Under review

I.Ouedraogo, M. J. Some, K.Oyibo R. Benedikter , et G. Diallo. "Evaluating a phone-based Interactive Voice Response system for reducing misinformation and improving malaria literacy ". *Information Technology for Development*.

Under review

I.Ouedraogo, M. J. Some, R. Benedikter, et G. Diallo. ""Measuring Health and e-Health literacy among hospitalized diabetic patients in low-income countries: a case study in Guinea and Burkina Faso." *Journal of Medical Internet Research*.

1 Introduction

Chapter 5 looks in detail at the development of mobile solutions tailored to facilitate access to health information for people with low literacy skills. It focuses on applying a user-centred design (UCD) methodology, a key approach to ensure the effectiveness and usability of the prototypes developed for this purpose.

The basis of this chapter is the realisation that effective dissemination of health information among vulnerable populations requires a strong focus on their needs, preferences and capabilities. To achieve this, the UCD method serves as a guiding framework that directs the design process towards user-centredness by focusing on the specific requirements of the target group.

One of the fundamental aspects examined in this chapter is the complex application of the UCD methodology. It describes a comprehensive iterative design process that includes understanding the users, capturing their specific requirements, iterative prototyping and evaluating the designs to determine their effectiveness and resonance with the target audience. The initial focus is on the compelling task of understanding the needs of users in the context of underserved populations, particularly in low-income countries. Notable case studies such as "Measuring health and e-health literacy among hospitalised diabetic patients in low-income countries" have been conducted to explore these needs in depth. These studies provide important insights into the level of health and e-health literacy among vulnerable groups and highlight gaps and challenges in understanding health-related information and digital health resources. In addition, the research extends to another important study, "Health Technology Preferences'," which looks at user preferences in relation to health technology interfaces and functions. By examining these preferences, the aim is to identify key design elements that can effectively bridge the gap in access to and use of health information, particularly in marginalised populations.

The following section takes an in-depth look at exploring the health literacy and eHealth capabilities of hospitalised diabetic patients in low-resource and underserved communities in SSA. The study focuses specifically on hospitals in Guinea and Burkina Faso and highlights the critical role of health literacy in the management of diseases such as diabetes in these challenging settings. Through a detailed account of the methods used, which include structured interviews, assessments and data analysis using robust statistical tools, this section demonstrates compelling results.

These findings emphasise the prevalence of low health literacy and eHealth literacy in the populations studied and highlight the urgent need for educational interventions and targeted strategies to promote digital health literacy in these communities.

In a parallel investigation, the chapter looks at the technology preferences of IDP in Burkina Faso to understand how populations interact with health information and how they prefer to access technological resources. The use of an experimental research design provides insights into participants' language preferences, user interface design inclinations, and content preferences, which is critical for tailoring health information technologies to their specific needs and preferences.

Essentially, this chapter serves as a comprehensive examination of the principles of user-centred design and their application in the development of mobile health information solutions. It brings together empirical evidence and findings from various studies to highlight the importance of a user-centred approach in addressing the complex issue of health information accessibility for low-literate populations in resource-limited settings.

2 Applying the User Centre design methodology

UCD is an iterative design process that involves understanding users, gathering their requirements, prototyping, and evaluating the designs.

2.1 User Understanding

To improve health literacy, we embarked on a journey to understand users' needs, with a particular focus on underserved populations, especially in low-income countries. Two important case studies were conducted to shed light on these needs. A study was on "Measuring health and e-health literacy among hospitalised diabetic patients in low-income countries" we aimed to assess the level of health and e-health literacy of these patients and to identify gaps and challenges in their understanding of health-related information and digital health resources. This study provided important insights that form the basis for tailoring solutions to the specific needs of this vulnerable patient group. Another study, "Health Technology Preferences'", focused on exploring users' health technology preferences. Our aim was at finding out which technological features and interfaces resonate most with users, particularly in underserved communities. By examining their preferences, we aimed to identify design elements that could effectively improve access to and use of health information.

2.2 Factors influencing the acceptability of Interactive Voice Systems among underserved communities: (case study 4)

As we start from the theoretical foundations of technology acceptance, it is imperative to place these concepts in the specific framework of the study specialisation — the 3-2-1 service. The 3-2-1 service, a form of IVR technology, is a beacon in the field of mHealth tools used to disseminate critical health information to underserved communities, particularly IDP's in Pazani camp. The theoretical background is based on the well-established Unified Theory of Acceptance and Use of Technology (UTAUT), a robust framework for understanding the complex dynamics of technology acceptance and use. This study ventures into uncharted territory and seeks to uncover the factors influencing the acceptance of different language versions of the 3-2-1 IVR service among IDPs in Burkina Faso. By exploring the multiple aspects of utility, privacy, hedonic value and enabling conditions, we do so with the practical aim of improving the effectiveness and acceptability of a vital health information platform in a resource-limited setting.

2.2.1 Context

The background of the study revolves around understanding the factors influencing the acceptance and adoption of the 3-2-1 service. This service, a form of IVR technology, aims to provide health information to underserved communities, specifically targeting Internally Displaced Persons IDP from the Pazani Camp. The study addresses the need for accessible and user-friendly technology solutions to bridge health information gaps in such communities. The study draws upon the UTAUT framework, a well-established model for studying technology acceptance and usage.

The IVR system is one of the various forms of mHealth tools that are often used by people with low literacy skills [Some, 2022b]. In other words, the use of an IVR service, which is an effective behaviour change [Some, 2022b], does not require users to be very literate [Kassavou, 2018]. Previous studies in low-resource settings have shown that IVR systems were effective in educating and engaging low-literate users during the Ebola epidemic [Wolfe, 2015]. For example, Maïke Winters et al. [Winters, 2021] used a radio play distributed via WhatsApp to debunk the widespread misinformation about health. In addition, during the COVID-19 pandemic in Burkina Faso, given the low health literacy [Nacanabo, 2021] associated with infodemics and misinformation that negatively impacted access to correct health information, an IVR service was deployed to improve COVID-19 literacy among students [Some, 2022b].

Although studies have shown that IVR systems have the potential to improve health literacy [Diedhiou, 2015], not much has been done to investigate their perception and acceptance among actual users. This study aims to fill this gap by examining the factors that determine the acceptability of different language versions of the service among IDPs in Burkina Faso, of an IVR system called "3-2-1 IVR Service"¹.

2.2.2 Methods

To gather data on the factors affecting the acceptance and adoption of the 3-2-1 service among the same Pazani Camp IDP population post-intervention, we employed an adapted version of the UTAUT questionnaire. This tailored questionnaire encompassed various constructs derived from the UTAUT model, including performance expectancy, effort expectancy, social influence, enabling conditions, and behavioral intention.

Participants recruitment:

Participants Recruitment 97 participants from the Pazani Camp IDP community, who had previously participated in the study evaluating the effectiveness of the 3-2-1 service in improving malaria health literacy, were selected. To mitigate bias, the inclusion criteria stipulated that participants must still be residing in the camp, willing to take part, and owners of mobile phones with an Orange (telecom) Burkina SIM card. Individuals who did not meet these criteria or expressed unwillingness to engage further with the 3-2-1 service were excluded from the study to maintain consistency and avoid potential bias in the results.

2.2.3 Data collection and analysis:

A verbal declaration of consent was obtained from all participants prior to data collection. The responses from the questionnaire were then analysed using statistical methods. Descriptive statistics were used to determine the mean and standard deviation of each item in order to obtain an overview of the participants' perceptions and attitudes towards the 3-2-1 service

1. <https://viamo.io/services/viamo-platform/>

after the intervention. In addition, a linear regression analysis was performed to test the hypotheses derived from the UTAUT model and to determine which factors significantly influence the acceptance and adoption of the service.

Assessment tool: The questionnaire was adapted from the earlier study by Oyibo et al. [Oyibo, 2021] which was based on the UTAUT [Venkatesh, 2003]. Appendix 2, Table 2 shows the different constructs we measured and their items. Apart from Perceived Ease of Use with 2 constructs and Intention to Use with 1 construct, the other constructs consist of 3 items. Their scales range from “strongly disagree (1)” to “strongly agree (5)”.

2.2.4 Utility value

In our study, utility refers to the degree to which the user believes that the 3-2-1 Service serves their health information need and/or facilitates access [Ahn, 2022; Famolari, 2002; Park, 2020]. The first two relationships in the research model relate to utility: Perceived Usefulness (H_1) and Perceived Ease of Use (H_2). Both relationships are based on earlier findings in the literature. They represent the two most important determinants of technology acceptance in the traditional TAM model [Kukuk, 2020; Oyibo, 2020]. For example, in the context of health, Van der Heijden [Van der Heijden, 2003] found that Perceived Ease of Use has a positive influence on the intention to use health websites. Moreover, in the contact tracing app domain, Kukuk [Kukuk, 2020] found that Perceived Usefulness has a positive relationship with intention to use. Moreover, in a systematic review of the factors that influence contact tracing app adoption, Oyibo et al. [Oyibo, 2022] reported many studies that found Perceived Usefulness and Perceived Ease of Use to be significant. Based on these previous findings, we hypothesize the following:

- H_1 : Perceived Usefulness of the 3-2-1 Service will have a significant influence on the intention to use it.
- H_2 : Perceived Ease of Use of the 3-2-1 Service will have a significant influence on the intention to use it.

2.2.5 Data protection beliefs

In this study, data protection beliefs entail privacy, security, and trust. Privacy, in the context of eHealth, refers to the individual's right to control the collection, use, or disclosure of their identifiable health information [Faqih, 2015; Avancha, 2012]. Moreover, security refers to the physical, technological, or administrative safeguards or tools used to protect identifiable health information from unauthorized access or disclosure [Faqih, 2015; Avancha, 2012]. More importantly, trust refers to the individual's trust in a service and/or operator in terms of protecting their best interest. The second set of hypotheses addresses users' data protection concerns Security and Privacy concerns (H_3) and Perceived Trust (H_4). They are based on previous findings in the literature [Oyibo, 2022]. For example, in a study of contact tracing app adoption, Boon-itt found that trust in health websites improves the intention to use them for seeking health information [Boon-itt, 2019]. Based on these prior findings, we hypothesize the following:

- H_3 : Security and Privacy Concerns about the 3-2-1 Service will have a significant influence on the intention to use it.
- H_4 : Perceived Trust in the 3-2-1 Service will have a significant influence on the intention to use it.

2.2.6 Hedonic value

Hedonic value refers to intrinsic motivation such as fun, enjoyment or pleasure derived from using technology. Research shows that it can impact the acceptance and use of technological tools [Alazzam, 2015]. According to a study conducted by Svendsen and colleagues, the most significant predictor of the intention to use a Mobile System Motivating for Physical Activity was found to be the user's intrinsic motivation [Svendsen, 2009]. In other words, the extent to which individuals perceive the system as enjoyable and fun to use played a crucial role in determining their intention to utilize it [Svendsen, 2009]. Based on these prior findings, we hypothesize the following:

- H_5 : Perceived Enjoyment of the 3-2-1 Service will have a significant influence on the intention to use it.

2.2.7 Facilitating conditions

Facilitating condition refers to the degree to which an individual believes that an organizational or technical infrastructure exists to support the use of the system [Venkatesh, 2003]. The fourth set of hypotheses (H_6) entails the Perceived Compatibility of the 3-2-1 Service with similar technological tools that the users had used in the past. According to a study conducted by Wu et al., it was found that Perceived Compatibility directly influences the behavioural intention to use mobile healthcare systems [Wu, 2007]. In other words, if individuals perceive that a mobile healthcare system is compatible with their needs, preferences, and existing technologies, they are more likely to have the intention to use it. Based on this prior finding, for H_6 , we hypothesize as follows:

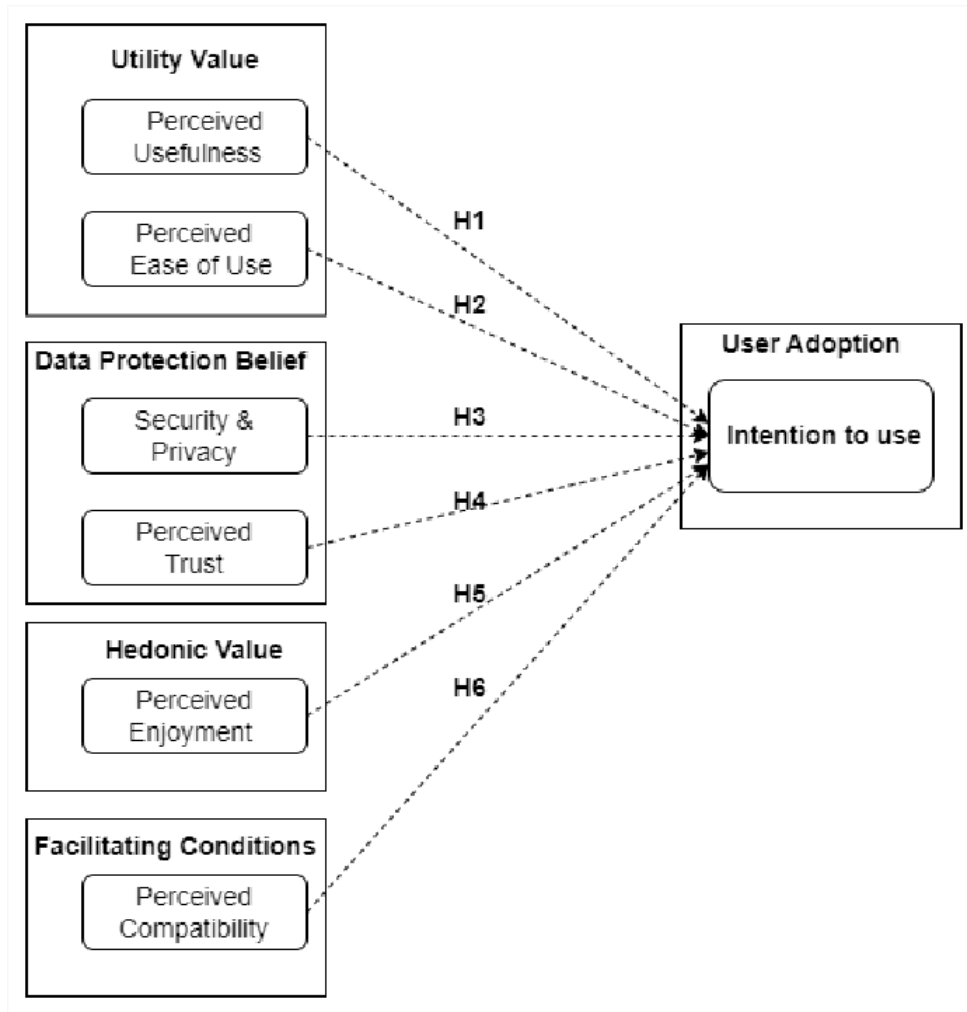


Figure 5.1 – Hypothesized UTAUT model of the adoption of 3-2-1 Service.

— H_6 : Perceived Compatibility of the 3-2-1 Service will have a significant influence on the intention to use it.

2.2.8 Results

To ensure the reliability and internal consistency of the measures used in our study, we conducted a reliability analysis using IBM SPSS Statistics 28. The results of this analysis, presented in Table 5.1, show that Cronbach's alpha values for each construct, i.e. perceived usefulness, perceived ease of use, security and privacy, perceived trust, perceived enjoyment, perceived compatibility and intention to use, were all equal to or greater than 0.7. These results meet established standards for reliability [DeVon, 2007] and confirm that the measures used in our study are robust and reliable to assess their respective constructs. In our study, a linear regression analysis was conducted to test several hypotheses aimed at understanding the factors influencing IDPs' intention to use the 3-2-1 service. The results are provided in table 5.2

2.3 Data Distribution

We examined the distribution of our data to determine if it approximated a normal distribution. Histograms were used to assess normality.

Age: In the control group, the majority of participants (30.9%) fall in the age group of 18–<24, followed by the age group of 25–<50 (48.5%). In the intervention group, there is a higher proportion of participants in the age group of 25–<50 (49.0%), followed by the age group of 18–<24 (30.6%). The distribution of age groups differs slightly between the two groups, with

Table 5.1 – Cronbach's alpha reliability

Construct	Number of Items	Cronbach's alpha values
Perceived Usefulness	3	0.86
Perceived Ease of Use	2	0.84
Security and Privacy	3	0.80
Perceived Trust	3	0.78
Perceived Enjoyment	3	0.84
Perceived Compatibility	3	0.70

the intervention group having a higher proportion of participants in the age group of 25–<50 compared to the control group. However, the overall distribution pattern is similar between the two groups.

Education: Both the control and intervention groups have a similar distribution of education levels, with the majority of participants being uneducated (67% in control, 67.3% in intervention). There is no significant difference in education level distribution between the two groups. **Income:** The income distribution is similar between the control and intervention groups. The majority of participants in both groups have an income of less than 40,000 CFA, with a smaller proportion having incomes between 40,000 and 100,000 CFA. There is no significant difference in income distribution between the two groups.

2.3.1 Findings

The **UTAUT** model was used to examine the factors that influence the adoption of the 3-2-1 mobile health information service. Our analysis focused on the relationship between various predictors, such as perceived usefulness and perceived ease of use, and users' intention to use the service. The results of our regression analysis provide information on the most important factors for acceptance. In Table 5.2

Table 5.2 – Verification of Hypothesis

Hypothesis	Predictor	Unstandardised coefficients		F	t	p	R2	Hypothesis
		β	Std. error					
H1	Perceived Usefulness	0.404	0.170	2.869	2.381	0.019	0.085	Yes
H2	Perceived Ease of Use	0.575	0.156	11.993	3.691	<.001	0.203	Yes
H3	Privacy and Security	0.279	0.085	4.014	3.301	0.001	0.115	Yes
H4	Perceived Trust	0.417	0.137	3.135	3.042	0.003	0.092	Yes
H5	Perceived Enjoyment	0.357	0.159	2.342	2.241	0.027	0.070	Yes
H6	Perceived Compatibility	0.191	0.057	5.768	3.346	0.001	0.157	Yes

Perceived ease of use: Our results show that users' intention to use the 3-2-1 service is primarily determined by the perceived ease of use of the system, accounting for 20.3% of the variance in intention to use. This is consistent with previous research findings and suggests that participants with higher levels of education [Campbell, 2017], who have advanced digital skills and knowledge, are more inclined to use technology-enabled mobile services because of their ease of use. Participants with higher education levels tended to adopt technology-driven services more readily, valuing ease of use as it facilitated their access to health information [Ali, 2022].

Perceived compatibility: We also observed a positive correlation between perceived compatibility and intention to use the 3-2-1 service. Perceived compatibility explained 15.7% of users' intention to use the service, indicating that participants perceived the service to be compatible with their previous experiences with similar technologies. This suggests that users perceived the 3-2-1 Service as compatible with the technologies they were familiar with, fostering their willingness to adopt [Klingberg, 2020].

Privacy and security issues: Our study revealed the influence of privacy and security concerns on **IDP** use of the 3-2-1 service, with this predictor explaining 11.5% of intention to use. This finding highlights the importance of addressing confidentiality concerns in resource-constrained settings and underscores the need to address patients' privacy fears for the acceptance of new technologies [Chang, 2013].

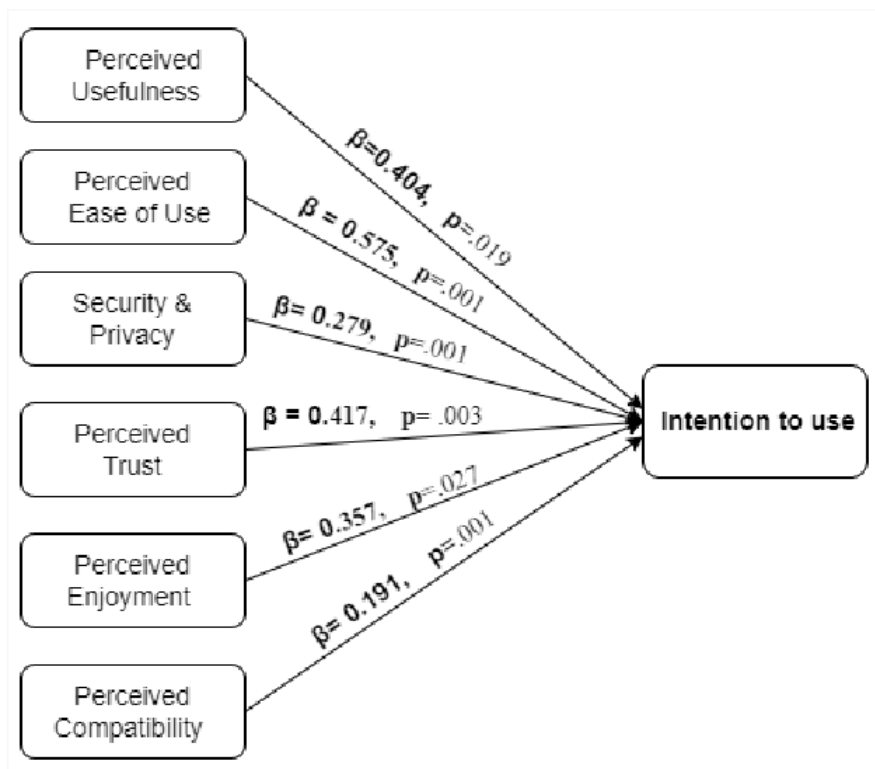


Figure 5.2 – UTAUT overall model of the intention to use the 3-2-1 Service.

Perceived trust: Perceived trust was another significant factor influencing intention to use, explaining 9.2% of users' intention. This confirms previous studies suggesting that trust plays a crucial role in patients' attitudes towards technology acceptance and use [Dhagarra, 2020].

Perceived enjoyment: Similar to previous studies, our study found that perceived enjoyment of the technology contributed to users' intentions to use the 3-2-1 service, accounting for 7% of intentions to use. This highlights the importance of users' perceived enjoyment of the technology to drive adoption [Ebnehoseini, 2020].

In summary, our study confirms that factors such as ease of use (perceived ease of use), security and privacy, trust, perceived enjoyment, portability and compatibility significantly influence the adoption of the 3-2-1 service. These findings highlight the critical role of user experience, trustworthiness and compatibility in the development and implementation of mobile solutions for underserved communities.

Participants' concerns about privacy and security emerged as significant, with 68% expressing apprehension about the confidentiality of their data. The role of trust in adoption was evident, as 71% of participants indicated a high level of trust in the service. Enjoyment of the service was evident, with 63% expressing satisfaction with their interaction.

Several conclusions can be drawn from these findings. Firstly, enhancing the perceived usefulness of the 3-2-1 service is crucial, requiring targeted communication and education campaigns to highlight its benefits for accessing health information. Improving user-friendliness is essential, catering to varying levels of digital literacy through ongoing improvements to the design and interface. Addressing privacy and security concerns is pivotal, necessitating robust security measures, transparent privacy policies, and effective communication to establish trust. Trust-building is central through reliable service delivery and adherence to privacy standards. Incorporating interactive and engaging elements is recommended to enhance user satisfaction and prolonged use. Lastly, compatibility with diverse devices commonly used by the target audience is critical, necessitating continuous efforts to adapt the service to different device specifications.

Overall, these findings provide practical insights for designing, implementing, and promoting the 3-2-1 IVR service and similar mobile health solutions.

2.3.2 Limitations

The study has its limitations as it only covers a limited sample and focuses exclusively on a single underserved community, namely the internally displaced persons in the Pazani camp in Burkina Faso. With a sample size of only 97 participants, the

study may not capture the diverse perspectives and needs of the different IDP communities in the region or other marginalised populations. To address this limitation, future research could expand the participant pool to achieve a more comprehensive and diverse representation of underserved communities to improve the generalisability of the findings and provide a more comprehensive understanding of technology adoption across different populations.

In addition, the exclusive use of participant self-report has limitations in terms of potential response bias or social desirability effects, which could affect the accuracy and depth of the information collected. To mitigate this limitation, future studies could utilise a mixed-methods approach that combines self-report with observations or qualitative assessments. The integration of different data collection methods could provide a more nuanced understanding of participants' perceptions and experiences of the 3-2-1 service and ensure a more comprehensive analysis of the factors influencing technology uptake in marginalised communities.

2.4 Exploring users' technology feature preferences in underserved settings (case study 5)

Navigating the landscape of health information technologies requires a nuanced understanding of patient preferences to ensure the effectiveness and acceptance of these tools. Given the underutilisation of health information technology and its potential mismatch with patient needs, this section focuses on Case Study 5, which specifically examines the preferences of users of technology features in underserved areas. Building on the evaluation of the impact of the 3-2-1 service on participants' malaria health literacy, this study shifts its focus to identifying how individuals prefer to interact with technology to access health information. A customised questionnaire will be used to capture participants' language preferences, user interface design and preferences regarding the design features of mobile health information services. This research aims to unravel the intricate web of user preferences and provide important insights for the development of user-centred, accessible and effective health information technologies.

2.4.1 Context

The underuse of health information technology suggests that the development of this technology may not be in line with patients' preferences and needs [Crossnohere, 2021]. This discrepancy highlights the importance of ensuring that health technologies are developed to meet the specific needs and preferences of the patients they are intended to serve. Understanding patient preferences is critical to developing user-friendly and effective health solutions that ensure technology is not only accessible, but also achieves its full potential. Incorporating patient feedback and preferences into the development process can lead to the creation of engaging, user-centred and ultimately useful health information technologies.

After completing the evaluation of the effectiveness of the 3-2-1 service in improving the malaria health literacy of our participants, we focused on gaining valuable insights into their technology preferences. Participants were asked to tell how they prefer to interact with technology to access health information. At this stage of data collection, a questionnaire was completed to elicit participants' preferences regarding technology. Key questions included language preferences, user interface design preferences, and preferences related to the design features of mobile health information services. By asking participants about these aspects, we aimed to gain a deeper understanding of their technological inclinations that could help us develop user-centred health information technology solutions. This holistic approach included both evaluation of intervention outcomes and exploration of participant preferences, and ultimately contributed to a more comprehensive assessment of our research objectives.

2.4.2 Methods

Participant recruitment: We used an experimental research design to investigate the effectiveness of a multilingual mobile IVR service to improve malaria health literacy among IDP in Pazani camp, Burkina Faso. Pazani camp is located in Arrondissement 9, about 15 kilometres from Ouagadougou, and serves as a shelter for many IDP's who have fled due to security concerns.

A total of ninety-seven (97) IDP from the camp were selected as participants for the study. The inclusion criteria for participation were defined as follows:

- A displaced person from Pazani camp: To ensure the relevance of our study, participants had to be IDP from Pazani camp.
- Willingness to participate: Participants had to express their willingness to voluntarily participate in the study.
- Possession of a mobile phone with Orange Burkina SIM card: To ensure that participants could actively work with the mobile IVR service, they had to have a mobile phone with an Orange Burkina SIM card.

- People who did not meet these criteria or were unable to complete the entire two-week study period, who refused to participate or who were unwilling to use the 3-2-1 service were excluded from the study.

Data collection: Our data collection process involved several important aspects:

- Demographic data: We collected general demographic information from participants, including details such as age, gender, education level and income level.
- Participants' technology preferences questionnaire: Participants were asked to indicate their preferences regarding different aspects of technology use, including language preferences, user interface preferences and preferences regarding design features for mobile health information services. The questionnaire used can be found in appendix 2.

Questionnaire used Since participants are low-literacy, questionnaires were translated into the local language by local experts following these procedures:

Two independent Dioula translators from the Ministry of Education, Burkina Faso, conducted the forward translation. Subsequently, a meeting was convened to address any discrepancies between the two translations and to reach a consensus. Cohen's kappa² Cohen's Kappa was utilized to assess agreement, yielding a percentage agreement of 66.66%. indicating fair agreement. The translated questionnaire was then administered to participants by three fluent speakers proficient in both the local language Moré and French.

Data analysis: We used the software IBM SPSS Statistics (SPSS28)³ to analyse the collected data. In the first step, we used descriptive statistics to obtain a comprehensive summary of participants' technology preferences. These preferences included choice of language, user interface and design features. This analysis was intended to provide valuable insights into how participants preferred to access health information via mobile devices.

2.4.3 Results

The results of the study shed light on critical factors that influence the design and accessibility of mobile health services.

As shown in Table 5.3, language preference emerged as a dominant factor, with an overwhelming majority preferring to use their local language. Specifically, 94.94% of female participants and 88.89% of male participants expressed a strong preference for health information in their local language. This preference was cross-age, as both participants under 18 and participants over 50 unanimously supported the use of the local language. Even among participants with different levels of education, an overwhelming 95.38% of the uneducated preferred the local language. Conversely, only a small percentage of the uneducated (4.84%) and those with primary or tertiary education opted for health information in French. It is noteworthy that 93.10% of participants with incomes below the poverty line also tended to choose the national language. These findings highlight the central role of language accessibility in ensuring that health information effectively reaches and benefits diverse populations.

In terms of user interface design, the language-based interface was the preferred choice of participants. Impressively, 81.01% of female participants and 77.78% of male participants favoured voice interfaces. This preference applied to all age groups, i.e. participants under 18 years, between 18 and 24 years, between 25 and 50 years and over 50 years, confirming the attractiveness and usability of voice-based interactions. This preference for voice interfaces was also observed among participants with different levels of education, which underlines the universal appeal of this type of interface.

However, when asked about the type of design of mobile health services, participants showed different preferences. Some 39.24% of participants indicated a preference for mobile services with serious-game elements that promote engagement and learning. In contrast, a larger majority, 60.76% of participants, preferred mobile health services without game elements. Gender played a role in this preference, as a higher percentage of men preferred game elements in mobile services. Age also played an important role, as younger participants (under 18 and between 18 and 24 years) tended to prefer serious games, while older participants (over 50) predominantly preferred game-free mobile services.

2.4.4 Findings

This study addressed participants' technology preferences and requirements in the area of mobile health information services. Several noteworthy findings emerged from this research.

Language preference: the results indicate a strong inclination among participants to use the local Moré language for mobile health services. In particular, a significant majority of female participants (94.94%) and people over 50 years of age (100%) preferred the local language. In addition, participants with lower levels of education, especially those without formal education (95.38%), showed a significant preference for the local language. Income level also played a role: 93.10% of participants earning less than the poverty line opted for the local language.

2. <https://idostatistics.com/cohen-kappa-free-calculator/#risultati>

3. <https://www.ibm.com/support/pages/ibm-spss-statistics-2801-documentation>

Table 5.3 – Participant's technology preference

Contents	Groups	Language preference				Interface preference						Content preference				Total Participants
		French language		More language		Text-based user interface		Voice-based user interface		Image-based user interface		Content with serious games		Contents without serious games		
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	
Gender	Female	4	5.33	75	94.94	14	17.7	64	81.01	1	1.27	31	39.24	48	60.76	79
	Male	2	12.50	16	88.89	3	16.67	14	77.78	1	5.56	8	44.44	10	55.56	18
Age (years)	18-<	0	0	6	100	1	16.67	5	83.33	0	0	3	50	3	50	6
	18-<24	3	11.11	27	90	6	20	24	80	0	0	19	63.33	11	36.67	30
	25-<50	3	6.82	44	93.62	7	14.89	38	80.85	2	4.26	19	40.43	28	59.57	47
	<50+	0	0	14	100	3	21.43	11	78.57	0	0	6	42.86	8	57.14	14
Education	Uneducated	3	4.84	62	95.38	10	15.38	54	83.08	1	1.54	26	40	39	60	65
	Primary school	1	6.67	15	93.75	3	18.75	13	81.25	0	0	6	37.50	10	62.50	16
	High school education	2	14.29	14	87.50	4	25	11	68.75	1	6.25	7	43.75	9	56.25	16
Income	<40 000 West CFA	6	7.41	81	93.10	15	17.24	70	80.46	2	2.30	36	41.38	51	58.62	87
	40 000 CFA – 100 000 CFA	0	0	4	100	1	25	3	75	0	0	1	25	3	75	4
	>100000 CFA	0	0	6	100	1	16.67	5	83.33	0	0	2	33.33	4	66.67	6

Preference for design interfaces: When it came to interface design, the majority of female (81.01%) and male (77.78%) participants expressed a preference for language-based interfaces in mobile health services. Remarkably, this preference for local language was consistent across different age groups, ranging from 78.57% to 83.33%. In addition, participants with different levels of education, including participants with no formal education (83.08%), primary education (81.25%) and at least secondary education (68.75%), tended to prefer the local language.

Preferred type of design: Regarding the type of design, the results revealed that a significant proportion of participants (60.76%) preferred mobile health services with games in general, while 39.24% preferred services with a serious game component. Male participants showed a differential preference, with 44.44% preferring services with games and 55.56% preferring services without games. Younger participants under 18 years of age and between 18 and 24 years of age leaned towards Serious Games, with 50% and 63.33% respectively expressing this preference. Conversely, 60% of participants over 50 preferred mobile health services without serious games.

These results highlight the marked preference for local languages, voice interfaces and a tendency to include games, especially among younger participants. These findings are consistent with previous research emphasising the importance of offering health information in participants' native language and the effectiveness of games in promoting engagement and motivation [EDIM, 2013; Mueller, 2020]. Understanding participants' technology preferences and needs is paramount to developing effective and user-centred mobile health information services that ultimately promote health literacy and engagement across different demographic segments.

2.4.5 Limitations

The study encountered several limitations that should be considered in future research endeavours. First, the results were predominantly based on participants' self-reports, which may lead to biases or inaccuracies due to subjective perceptions or social desirability. This reliance on self-reported data may not fully capture the nuanced and dynamic nature of user preferences, potentially limiting the depth of understanding of their actual interaction with the technology. To overcome this limitation, future studies could integrate objective measures or behavioural analysis, such as tracking user interactions with the technology or conducting usability tests, to validate stated preferences and provide a more comprehensive understanding of user behaviour.

Second, the study focused primarily on preferences in a specific demographic and geographic context, namely IDPs in a specific camp in Burkina Faso. This narrow scope limits the generalisability of the results to broader population groups or other cultural contexts. To counter this limitation, future research could take a more diverse and comprehensive approach and include participants from different underserved settings, cultural backgrounds, and geographic regions. This broader inclusion could provide a more holistic view of the technology preferences of underserved populations and offer insights into the variability and commonalities between different communities. In addition, conducting comparative studies across different regions or populations could help identify patterns and variations in technology preferences, contributing to the development of universally applicable health information technologies tailored to the diverse needs of users.

2.5 Health and e-Health literacy among diabetic patients in low-income countries: case study 6)

Health literacy and eHealth capabilities are critical components of effective chronic disease management, especially in low-resource and underserved communities facing the burden of diseases such as diabetes. As highlighted in the previous sections, the study focuses on measuring health literacy and eHealth skills among hospitalised diabetic patients in low-income countries. This section details the specific methods used to assess this knowledge among participants in the hospital of Donka, Guinea, and the hospital of Sanou Sourou, Burkina Faso. Understanding the context of diabetes prevalence in these regions, the challenges associated with inadequate health literacy and the potential of digital solutions such as mobile health apps and telemedicine,

provides the basis for a comprehensive examination of the study's methods and results. The aim is not only to identify existing levels of health literacy, but also to shed light on the critical role of traditional and digital education in empowering patients to effectively self-manage and improve health outcomes in a challenging healthcare environment.

2.5.1 Context

Diabetes, an urgent global public health problem, is particularly alarming in resource-poor and underserved communities. Diabetes is among the leading causes of global mortality, with a rapid increase in SSA, where the number of affected adults is expected to reach 629 million by 2024 [Analike, 2022]. Complications such as end-stage renal disease, amputations and blindness are common consequences, often due to inadequate management of critical risk factors such as blood pressure, cholesterol levels and glycemic control [Mbanya, 2003; Mogessie, 2022].

The critical role of health literacy in the management of diabetes is becoming increasingly apparent in these contexts [Chen, 2014]. Inadequate health literacy is associated with deficits in diabetes knowledge and self-management, which burdens healthcare providers and hinders effective patient engagement [Craig, 2020; Carolan, 2014]. Health literacy in diabetes encompasses a patient's ability to understand, communicate and effectively apply medical information for self-management, a challenge in populations with limited resources and educational opportunities [Lee, 2018; Al Sayah, 2013].

Comprehensive education is essential for effective diabetes self-management. It is often delivered through printed materials and verbal instructions, and requires advanced health literacy. Digital solutions such as mobile health apps *mHealth* and telemedicine have emerged as potential bridges to address health inequalities. However, ensuring that these technologies are accessible in different cultural and linguistic settings, as well as when digital literacy is low, remains a major challenge [Teitelman, 2018; Kreps, 2017; Hughson, 2018]. The concept of eHealth, which emphasises the ability to find, understand and evaluate health information from electronic sources, has gained prominence but requires tailored approaches in these communities [Norman, 2006a; Chesser, 2016].

This study examines the health literacy and eHealth skills of diabetic inpatients in underserved communities in SSA, specifically Donka Hospital in Guinea and Sanou Sourou Hospital in Burkina Faso. The aim is to provide information for interventions, educational initiatives and the development of accessible *mHealth* solutions critical to improving self-management skills, treatment outcomes and overall well-being in these challenging contexts [Lin, 2020; Kreps, 2017; Hughson, 2018].

2.6 General knowledge about Guinea

The healthcare system in Guinea faces the challenge of a low adult literacy rate of 30 % [Diallo, 2019], exacerbating the difficulty in effectively communicating and disseminating essential health information among the population. With over half of the population under 18 years old and many living in rural areas, ensuring access to comprehensible and culturally appropriate health information becomes crucial for promoting better health outcomes. Addressing these vulnerabilities demands a comprehensive approach that considers the intersection of socio-political challenges, healthcare system limitations, and the specific needs of the population, particularly in terms of improving health literacy and promoting equitable access to healthcare services.

2.7 Language

The study revolves around enhancing health literacy in West African languages, specifically focusing on Fula in Guinea, Moré, and Dioula (or Jula) in Burkina Faso. The primary aim is to address health literacy challenges by considering the nuanced dynamics of local and national language use. Recognizing the pivotal role of linguistic and cultural factors in health communication, the research targets the imperative task of bridging language barriers to promote effective health literacy in diverse linguistic landscapes. Fula, also known as Fulfulde or Fulani, belongs to the Senegambian branch of the Niger-Congo language family. Spoken by approximately 25 million people⁴, Fula is prevalent in various regions across West Africa. In Guinea, the health literacy challenges among the Fula community arise due to a low literacy rate, underscoring the necessity for oral communication in health education.

Addressing health literacy challenges in these underserved communities requires assessing education levels and e-health literacy, actively engaging the community, using verbal communication methods, translating materials into specific languages and dialects, and ensuring cultural competency. These efforts are particularly important as Fula, Moré and Dioula together make up a significant percentage of the population in their respective regions. Adapting health communication to the linguistic and cultural context of these communities will effectively improve health literacy and recognise its importance to the wellbeing of a significant proportion of the local population.

4. <https://celt.indiana.edu/portal/Fulfulde/index.html>

2.7.1 Methods

The study was conducted in May 2022 in two health facilities: The Hospital of Donka in Guinea and the Hospital of Sanou Sourou in Burkina Faso. The flowchart shown in Figure 5.3 was followed. Initially, 92 potential participants were approached to take part in the study. However, some individuals were excluded due to factors such as a lack of diabetes diagnosis or unwillingness to participate. This resulted in a final cohort of 45 eligible participants in Donka and 47 in Sanou Sourou who actively participated in the study. The study was approved on ethical grounds and all participants had provided verbal informed consent before data collection. Eligibility criteria included that participants were at least 18 years old, had a confirmed diagnosis of diabetes, gave informed consent and spoke either the local languages (Dioula in Burkina Faso, Fula in Guinea) or French.

Data collection was facilitated by structured face-to-face interviews conducted in local languages by trained research coordinators.

In terms of research methodology, a within-group design was implemented, requiring each participant to complete both the eHealth Literacy Scale (eHEALS) and the BHLS (see Appendix 2 Table 4). Participants were given clear instructions to ensure that the answers were correct based on their knowledge. To ensure cultural relevance, validated French versions of eHEALS and BHLS were used, with translations into native languages available for Burkina Faso and Guinea.

Questionnaire translation procedure Two independent translators proficient in Dioula, employed by the Ministry of Education in Burkina Faso, performed the initial translation. Following this, a meeting was organized to reconcile any disparities between the two translations and establish a unified version. Cohen's kappa⁵ Cohen's Kappa was utilized to assess agreement, yielding a percentage agreement of 69.23% indicating fair agreement. The translated questionnaire was then administered to participants by 4 fluent speakers proficient in both the local languages Dioula, Fula and French.

These tests aimed to assess participants' abilities to navigate electronic health information and understand their health status, medical forms and hospital materials. The internal consistency and reliability of these assessments were assessed using Cronbach's alpha. The research process followed a structured sequence for each participant, beginning with a demographic questionnaire and continuing with the BHLS and eHEALS assessments. Data analysis included descriptive statistics to examine the demographic data, the BHLS results and the eHEALS results.

Assessment tools: Two main assessment tools were used in this study. The eHEALS tool consists of eight items rated on a 5-point Likert scale and was used to measure eHealth literacy (see Appendix. It assesses individuals' skills in using electronic health information. Scores on the eHEALS scale can range from 8 to 40, which allows participants to be classified as having low eHealth literacy (eHEALS < 26) or high eHealth literacy (eHEALS > 26) [Chaniaud, 2022; Perrin, 2021b; Richtering, 2017]. The BHLS, which includes three questions on a 5-point Likert scale, was used to assess patients' health literacy in terms of their understanding of their health condition, their ability to complete medical forms, and their understanding of hospital materials [McNaughton, 2015; Wallston, 2014; Willens, 2013]. BHLS scores can range from 3 to 15, so respondents can be categorised as having low health literacy (total score 3-9) or adequate health literacy (BHLS score 10-15) [Al Sayah, 2013; Chew, 2008; Perrin, 2021a].

Data analysis: Data analysis was conducted using IBM SPSS Statistics version 28. The analysis focused on participants who agreed with at least five of the statistical analyses performed. Descriptive statistics were applied to demographic characteristics, technology use variables and eHEALS scores. Summary eHEALS scores were obtained by summing the responses to the eight eHEALS questions indicating the level of eHealth knowledge, and participants with a score of 26 or higher were considered to have high eHealth knowledge.

Ethical approval and declaration of consent of the participants: This study was conducted in strict compliance with the ethical principles outlined in the Declaration of Helsinki. Ethical approval was granted by the Ethics Committee of the University Hospital of Sourou Sanou, Burkina Faso, on 28 January 2022 (reference number: 2022/E 112), and the Ethics Committee of the National Directorate of Epidemiology and Disease Control, Guinea, approved on 30 March 2022 (reference number: 246/DNGLEM/MS/2022). Before participation in the study, all participants provided verbal informed consent stating that they voluntarily agreed to participate in the study. Strict measures were taken throughout the research process to ensure data protection and confidentiality of participants' data and to protect their rights and welfare.

2.7.2 Results

Demographic data: The demographic data of the hospitals in Donka and Sanou Sourou show similarities. As illustrated in Table 5.4 Donka had a slightly higher proportion of female participants (64.4%) than Sanou Sourou (57.4%). Both hospitals had a comparable age distribution, with the majority between 25 and 50 years of age.

Internal consistency and reliability of the instruments: The eHEALS and BHLS scales showed internal consistency in both the Fula and Dioula populations. As shown in Table 5.5 Cronbach's alpha values were exceptionally high at 0.98 for the eHEALS

5. <https://idostatistics.com/cohen-kappa-free-calculator/#risultati>

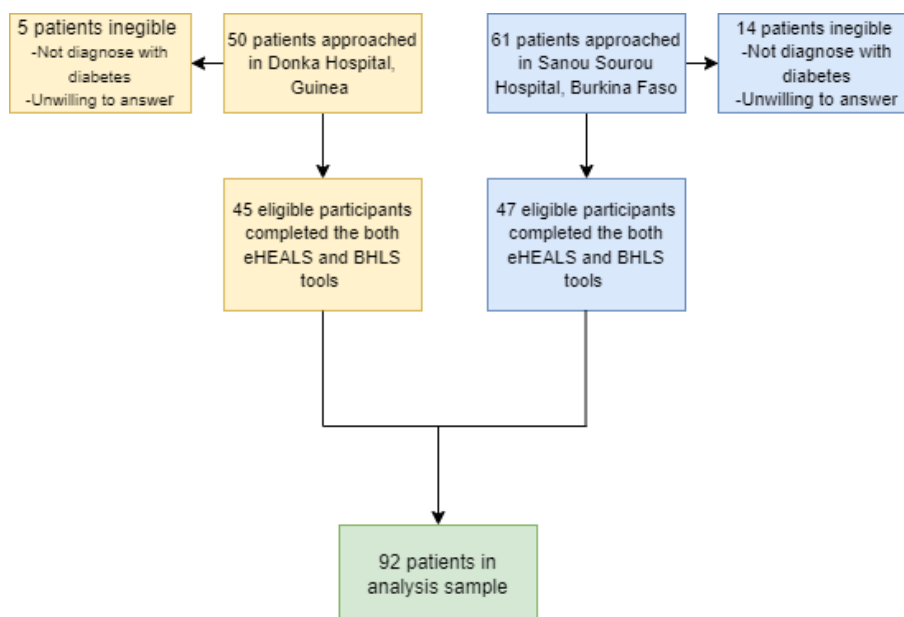


Figure 5.3 – Flowchart of the study.

Table 5.4 – Sample Characteristics

Contents	Groups	Donka Hospital Guinea (n=45)		Sanou Sourou Hospital Burkina Faso (n=47)		t	Sig 2 tailed
		n	%	n	%		
Gender	Female	29	64.4	27	57.4	1.116	0.271
	Male	16	35.6	20	42.6		
Age (years)	18-<	2	4.4	1	2.1	0.577	0.667
	18-<24	3	6.7	2	4.3		
	25-<50	22	48.9	23	48.9		
	<50+	18	40	21	44.7		
Education	Uneducated	28	62.2	28	59.6	-0.502	0.618
	Primary school	17	37.8	19	40.4		
Income	40 000 FCFA ⁶ or <500 000 <GNF ⁷	23	51.1	27	57.4	0.374	0.711
	40 000 CFA >= and <100 000 FCFA or 500 000 GNF >= and <1 500 000 GNF	11	24.4	13	27.7		
	>100 000 CFA Or >1 500 000 GNF	11	24.4	7	14.9		
Technology Access	Don't own a cellphone	7	15.6	6	12.8	-0.372	0.723
	Own cellphone	10	22.2	11	23.4		
	Own smartphone	28	62.2	30	63.8		
Technology use	Never Internet use	16	35.6	19	40.4	0.368	0.715
	Use sometimes for basic (social media such as WhatsApp)	16	35.6	20	42.6		
	Internet use regularly for information (including health information)	13	28.9	8	17		

scale in both populations 0.91 for the BHLS scale in the Fula population and 0.97 in the Dioula population. These results confirm the reliability of the two scales in effectively measuring the intended constructs in both populations.

Table 5.5 – Cronbach's alpha reliability

Scales	Cronbach's alpha values Fula	Cronbach's alpha values Dioula
eHEALS	0.982	0.983
BHLS	0.919	0.977

Assessment of participants' health literacy and eHealth literacy: As illustrated in Figure 5.4 the participants' health literacy and eHealth literacy scores were found to be low. In Donka, a proportion (73.3%) of respondents showed low health literacy, while only 35.6% showed adequate health literacy. In Sanou Sourou, the picture was similar: 78.7% of respondents had low health literacy and only 21.3% had adequate health literacy. In addition, both hospitals had low eHealth literacy, which means that they have limited ability to use digital technologies for health-related purposes.

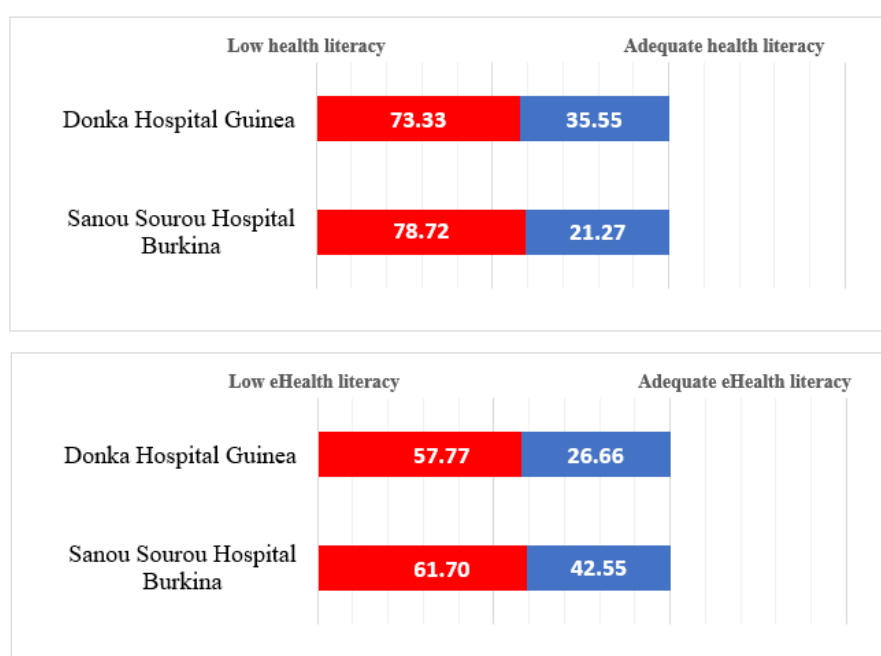


Figure 5.4 – Participants' overall health literacy and eHealth literacy level in study sites

2.7.3 Findings

The study examined the health literacy and eHealth skills of diabetic inpatients at Donka Hospital in Guinea and Sanou Sourou Hospital in Burkina Faso, both located in underserved communities with limited resources [Lin, 2020; Hughson, 2018]. When the demographic data was analysed, it was found that both hospitals had similarities. Participants were predominantly female and most respondents fell into the 25-50 age group, indicating a relatively young population. The majority had little or no formal education. Access to technology, especially smartphones, was widespread, but there was a significant deficit in health literacy [Lin, 2020].

In terms of health literacy, 35.6% of respondents in Donka had a high level of diabetes-related health literacy, while 21.3% in Sanou Sourou had adequate health literacy.

2.7.4 Limitations

This study has certain limitations that should be considered in order to understand its broader implications. First, the instruments used to measure health and eHealth literacy, namely eHEALS and BHLS, have not been previously validated in local languages such as Dioula or Fula with large populations. This lack of validation may limit the generalisability of the results, especially in the local context. In addition, the study was conducted in specific hospitals in Guinea and Burkina Faso, which may limit the extrapolation of the results to other low-income countries or to other healthcare facilities. In addition, the analysis did not perform significance tests for key demographic factors such as age, education and income, as it is difficult to interpret the significance of the data. Therefore, the study may not be able to accurately conclude whether or not such differences exist.

3 Identification of user requirement

User requirements are the foundation on which the design process of any system is built. They provide information about what users expect and need from the system and serve as a guide for the designers. These requirements can be divided into two different types: functional requirements and non-functional requirements. Each of which plays a specific role in the system design.

Functional requirements: Functional requirements are the building blocks of system functionality. They describe the specific functions and capabilities that a system must have to meet user expectations. For example, in the area of mobile health information services, functional requirements might dictate the provision of content in the local language, the integration of Voice-based User Interfaces (VUIs) to enhance user interaction, and the inclusion of engaging elements such as serious games. In essence, the functional requirements define how the system will enable users to achieve their goals, which has a significant impact on the overall user experience.

Non-functional requirements, on the other hand, go beyond functionality and include aspects such as usability, security, reliability and scalability. These requirements focus on how the system works and what features it should have. Non-functional requirements include ensuring data security to protect user data, ensuring usability for people with limited literacy skills, and optimising the system for low-bandwidth networks to improve accessibility. These requirements are critical to ensure that the system meets certain standards and user expectations while emphasising overall quality and performance. Key findings from our research highlight the importance of meeting both functional and non-functional requirements, particularly for those with lower levels of education living in underserved communities. Language accessibility emerges as one of the most important functional requirements, as users find content in their local language very important for better accessibility and understanding. The integration of a language-based user interface proves to be crucial, as users with limited literacy skills find language interfaces more user-friendly. Integrating engaging elements such as serious games can motivate behaviour change and improve the learning experience, especially for younger users. The non-functional requirements are equally important.

Usability is one of the most important non-functional requirements. It underlines the importance of developing a simple, clear and efficient system that is also suitable for users with low literacy skills. Data security and privacy measures are essential to allay user concerns and build trust through transparent data collection, use and sharing practices. Cultural sensitivity is essential, as respect for cultural norms and values encourages user engagement. Finally, affordability is also an important consideration. Efforts are made to minimise data consumption and optimise the system for low-bandwidth networks to ensure accessibility for users with limited resources.

Considering these insights in the design and development of mobile health information services can lead to tailored solutions that meet the specific needs and challenges of people with lower levels of education in underserved communities. These tailored solutions have the potential to increase health literacy, improve access to important health information, and ultimately contribute to better health outcomes in these special populations.

3.0.1 Functional requirements

Language accessibility: Users place a high value on health information being provided in their local language. This improves accessibility and ensures effective understanding and use of the content. Incorporating local languages into mobile health information services has shown that they can improve access to health care in remote areas.

Voice-based interaction: Users with low literacy skills find voice interfaces more user-friendly than text-based interfaces. Therefore, the inclusion of a Voice-based User Interface (VUI) that allows interaction through voice commands or recognition greatly improves accessibility and usability for this user group.

Engagement through serious games: The integration of engaging and interactive features such as serious games into mobile health information services proves to be beneficial, especially for younger users. Serious games can motivate behaviour change and enhance the learning experience by encouraging active participation in health management.

3.0.2 Non-functional requirements

Usability: Usability is one of the most important non-functional requirements. The system must be designed to be simple, clear and efficient so that it remains effective and user-friendly even for people with low literacy skills.

Data security and privacy: Users express concerns about data protection. Implementing robust security measures to protect user data is essential. Building trust through transparency in data collection, use and sharing is crucial for user acceptance.

Cultural sensitivity: Recognising and respecting the cultural norms, values and beliefs of the target population is critical for user engagement and acceptance within the community. Providing culturally appropriate health information increases relevance and connectedness.

Affordability: The affordability of the mobile health information service is critical. This includes minimising data usage and optimising the system for low bandwidth networks to reduce costs and improve accessibility for people with limited resources.

By incorporating these important insights into the design and development of mobile health information services, designers can create customised solutions that meet the specific needs and challenges of low-literate people in underserved communities. These solutions have the potential to promote health literacy, improve access to important health information and contribute to better health outcomes in these populations.

4 Designing a prototype of an **IVR** Service to improve Covid-19 literacy among Low literates

Before we delve into the details of the AI-powered IVR system, it is of utmost importance to emphasise the fundamental principles underlying its design. The development of this transformative technology was based on a user-centred approach that takes into account the diverse needs and challenges faced by people with low literacy skills during the COVID-19 pandemic. The development prioritised accessibility, linguistic integration and ease of use to ensure that the end users, particularly the students in Bobo Dioulasso, Burkina Faso, were at the centre of the decision-making process.

This section describes the user-centred design principles that formed the basis for the subsequent development and implementation of the IVR system. The overarching goal was to create a tool that not only delivers vital health information, but does so in a way that resonates with the target audience and promotes engagement and understanding amidst the complexities of a global health crisis.

4.1 Context

During the COVID-19 pandemic, Africa faced significant challenges in disseminating health information to vulnerable populations. Despite the continent experiencing a relatively lower impact from the pandemic, weak healthcare systems, high illiteracy rates, and the predominance of foreign languages in health services created substantial barriers, particularly for rural communities.

In response to these challenges, the PATIENT-COVID-19 project⁸ implemented innovative digital solutions. Among these tools, a chatbot was specifically designed and developed to augment COVID-19 vaccine literacy among undergraduate students in Burkina Faso [Some, 2022a]. Notably, the project also established a mobile Interactive Voice Response (IVR) system tailored to disseminate verified COVID-19-related health information [Some, 2022b]. The design process of the IVR system considered essential requirements, emphasizing the integration of local languages and voice interfaces. The design process carefully considered identified requirements, including the integration of local languages and voice interfaces.

To assess the effectiveness and usability of this service, a comprehensive usability test was conducted among high school students in Bobo Dioulasso, Burkina Faso. The primary objective of this test was to evaluate the functionality and user-friendliness of the IVR service. The insights gathered from this evaluation provide valuable information about the service's efficiency and its potential impact in making essential health information accessible, especially during the ongoing pandemic.

4.2 Design process

A comprehensive and careful design process was carried out during the development of the AI-supported **IVR** to promote literacy during the COVID-19 pandemic. The graphical user interface for the **IVR** service can be found in Figure 5.5 It provides a comprehensive overview of the steps involved:

8. <https://www.patient-covid19.org/about.html>

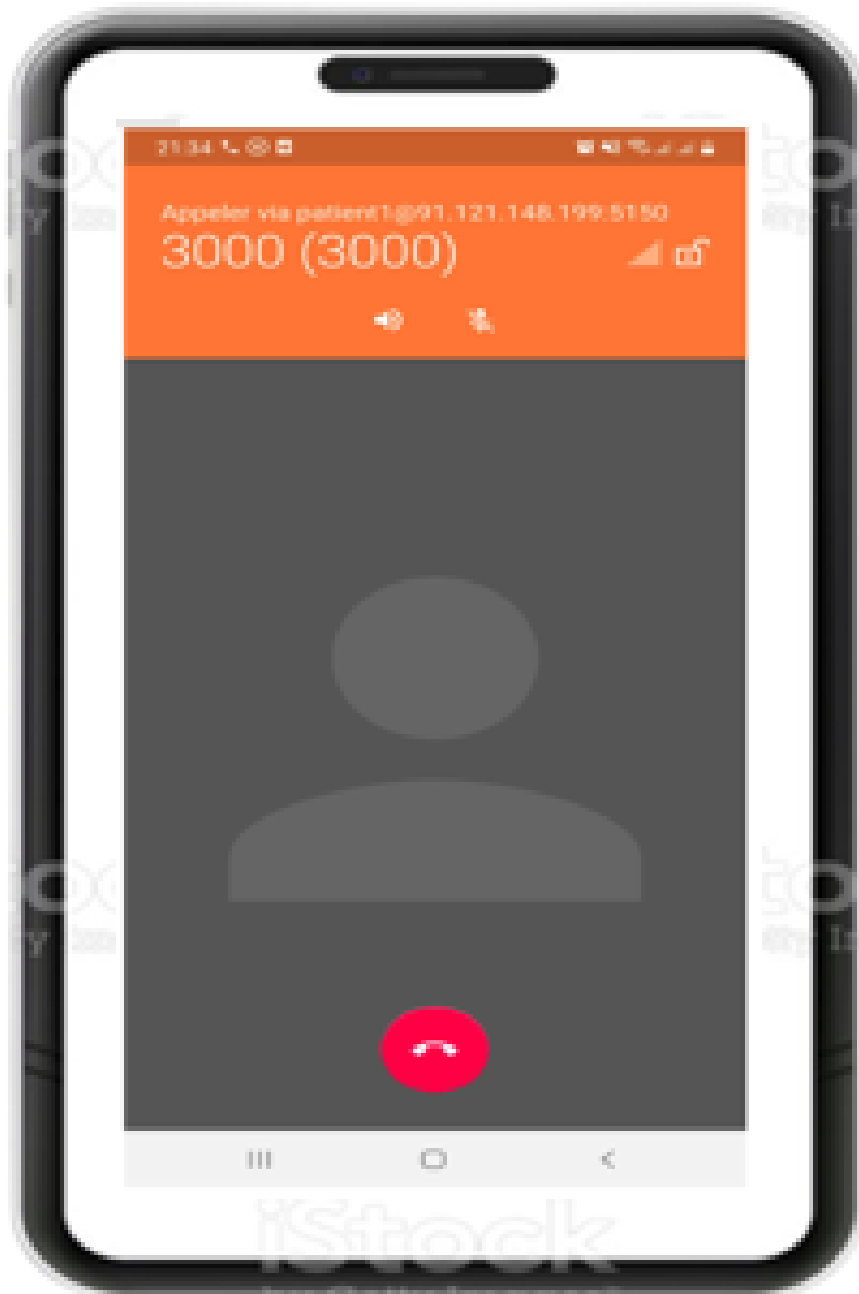


Figure 5.5 – GUI of the IVR service

5. Usability evaluation of the prototype among Burkina Faso high school students: case study 7)

Identifying the need: The journey began with the recognition of the urgent need to address the information gap around COVID-19, particularly in resource-poor regions with limited literacy skills. The main focus was on providing accessible and accurate health information.

Setting clear goals: To effectively address these needs, clearly defined objectives were set. Key objectives included the creation of an IVR system capable of disseminating validated COVID-19 health information in the Dioula language.

Use of AI technologies: A key aspect of the development process was the strategic integration of AI technologies. NLP and other AI components were integrated into the IVR system to increase its intelligence and effectiveness.

Language selection: Given the multiple languages spoken in the target region, careful selection of languages was a fundamental aspect of the design process. The service was carefully tailored to include several languages, with a particular focus on the Dioula language. This focus was crucial to ensure that the information provided was easily understood and accessible by local communities in Bobo Dioulasso, Burkina Faso.

To ensure the accuracy and reliability of the information conveyed, the content, consisting of questions and answers on the causes, consequences and prevention of Covid-19, was sourced from the World Health Organisation's Questions and Answers Hub portal (WHO)⁹. They were then expertly translated into the Dioula language by a local Dioula language expert. This rigorous translation process ensured that the information disseminated through the IVR system was not only linguistically appropriate but also trustworthy and compliant with global health guidelines.

Setting up the IVR system: The technical infrastructure was built and included essential elements such as the Asterisk PBX technology¹⁰, the W3C Voice Extensible Markup Language (VoiceXML 2.1)¹¹ and a VoiceXML interpreter¹². These components formed the backbone of the IVR system.

Accessibility and usability: Throughout the development process, the highest attention was paid to accessibility and usability. The IVR system was designed to be available and user-friendly 24/7, with Dual Tone Multi-Frequency (DTMF) tones facilitating user input via a keypad.

Menu structure: To ensure a seamless user experience, the menu structure has been carefully crafted. The number of menu options has been intentionally limited to three to simplify navigation for the user. Sufficient time has been allocated for user input and clear, concise instructions have been given to guide the user through the menu navigation.

Language preference: At the start of the service, users had the option to select their preferred language, including local languages such as Dioula, to ensure access to information in a language they were familiar with.

Integration and rigorous testing: Once all system components were integrated, extensive usability testing was conducted. Users, including students in Bobo Dioulasso, Burkina Faso, actively participated in the tests to evaluate the functionality and usability of the IVR service.

Deployment: After successful testing and taking into account feedback from users, the IVR service was deemed ready for deployment. A toll-free number was assigned to improve accessibility to the wider community.

Continuous improvement: The design process was not a static endeavour but followed the principle of continuous improvement. Mechanisms were put in place to continuously monitor and collect feedback to provide insights for iterative improvement of the IVR service.

Challenges addressed: It is noteworthy that due to resource constraints, Text-To-Speech (TTS) technology was not used. This highlights the practical challenges encountered during the design process and the resource-efficient approach taken to overcome them.

Overall, the development of the AI-enabled IVR service to improve literacy during the COVID-19 pandemic was a holistic effort that included needs identification, clear goal setting, strategic use of AI, careful language selection, technical infrastructure set-up, prioritisation of accessibility and usability, thoughtful menu structure design, rigorous testing, deployment and an unwavering commitment to continuous improvement. In addition, the innovative approach to finding solutions with limited resources ensured the effectiveness of the service in delivering important health information in the Dioula language.

5 Usability evaluation of the prototype among Burkina Faso high school students: case study 7)

As we move from the detailed design and development of the AI-powered IVR service to the crucial usability test phase, it is essential to examine the findings from the evaluation of the prototype by high school students in Bobo Dioulasso, Burkina Faso. This phase addresses the effectiveness and usability of the IVR service and provides valuable information on its impact

9. <https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub>

10. <https://www.asterisk.org/>

11. <https://www.w3.org/TR/voicexml21/>

12. <https://github.com/JVoiceXML/JVoiceXML>

on communicating COVID-19 information and improving the health literacy of the target group [Some, 2022b]. The following sections provide an overview of the methods used, the results obtained and the key findings that shed light on the usability of the service and its potential to bridge information gaps in the healthcare system during the ongoing pandemic.

5.1 Methods

The assessment of the usability of the IVR prototype was conducted with a quantitative methodology using the System Usability Scale questionnaire (SUS) [Bangor, 2009]. This pre test of this proof aimed to assess how user-friendly and effective the service COVID-19 provides information in the Dioula language. To this end, a group of small group of 18 high school students from Bobo Dioulasso, Burkina Faso, were recruited for the test. The recruitment process was facilitated in collaboration with school headmasters, and parental consent was obtained for participants under the age of 18. To be eligible, participants had to meet certain inclusion criteria. These included proficiency in the Dioula language, ownership of a smartphone (Android or iOS) and enrollment as a high school student in the city of Bobo Dioulasso.

Data collection took place in January 2022. Before the start of the study, all participants attended an orientation session led by the study director and research assistants. During this session, participants were familiarised with the study protocols and given an overview of the IVR service. They also had the opportunity to make an initial IVR call in the presence of the research team and ask any questions they had.

Following the orientation session, participants were instructed to download the Zoiper softphone, a free application that allows Voice-over IP (VoIP) calls to be made through the app associated with the IVR service, PBX. Participants had to create an account in the Zoiper app with an identifier (ID) and password. After logging in, they were given access to the toll-free number 3000, which they could use to make calls via the Zoiper keypad.

After their interaction with the IVR service, participants were asked to complete the questionnaire SUS (see in Appendix 2 in Table 6. This questionnaire, which was filled out via a Google form, consisted of 10 questions asking participants to rate the usability of the IVR service. The questionnaire specifically aimed to find out how participants felt about the service after using it for 3 hours.

The data collected from the completed SUS questionnaires was subjected to quantitative analysis using established methods and statistical procedures. This pretest process provided valuable insights into the user-friendliness of the IVR service and shed light on its effectiveness in providing COVID-19 information and improving the literacy skills of the target group, high school students in Bobo Dioulasso.

5.2 Results

The Results of the study are summarised in Figure 5.6. A total of 18 participants, with 12 being women and 6 men, all aged between 12 and 20 years old, participated in the study. The usability assessment, as illustrated in Figure 5.6, yielded highly positive results. All participants unanimously agreed that the IVR service was user-friendly, requiring no technical assistance or extensive training. A majority of participants 14/18 expressed confidence in using the IVR service, and 13/18 indicated a strong desire to use IVR frequently. A minimal percentage of participants 3/18 found the IVR service cumbersome, and only 2/18 perceived it as overly complex.

Regarding functionality, 13/18 found that the various functions of the service were well-integrated. The usability of the service was numerically interpreted using the SUS scoring procedure [Bangor, 2009]. The resulting average score was 78.75. Previous research suggests that a SUS score above 68 can be considered above-average usability, making the obtained score of 78.75 acceptable score for the test [Bangor, 2009; Thirumalai, 2022].

5.3 Findings

The test involved 18 participants, including 12 women and 6 men aged between 12 and 20 years. Figure 1 illustrates the highly positive results of the usability assessment. All participants found the IVR service is user-friendly and does not require technical support or extensive training. 14/18 expressed confidence in using the IVR service and 13/18 expressed a strong desire to use IVR frequently. A small proportion 3/18 found the IVR service cumbersome and only 2/18 found it overly complex.

In terms of functionality, 13/18 agreed that the various functions of the service were well integrated. The System Usability Scale (SUS) assessment procedure was used and resulted in an average score of 78.75, indicating an acceptable test score [Bangor, 2009; Thirumalai, 2022].

[Some, 2022b] demonstrates usability of the developed IVR service and indicates its potential to improve COVID-19-related health literacy. Participants with low literacy skills found the service user-friendly and did not require technical assistance. In addition, 13 participants expressed a strong interest in using it frequently. The inclusion of the national language in the system

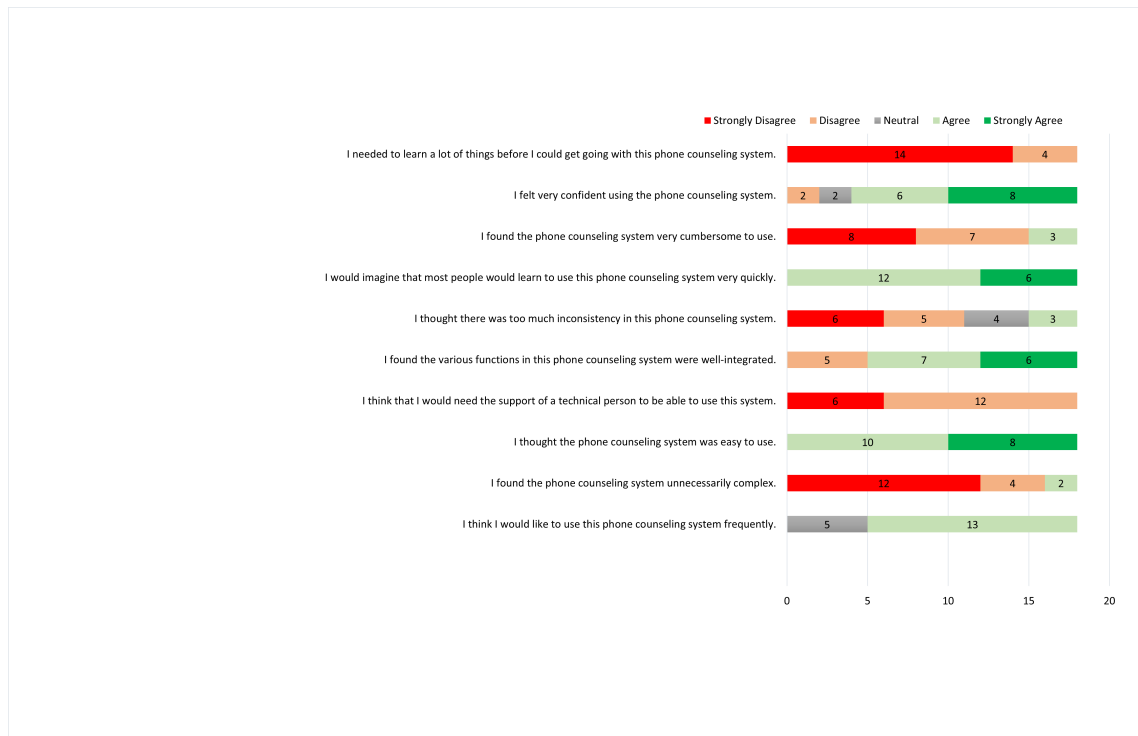


Figure 5.6 – System Usability Scale with answers

was well received, as it increases accessibility and the ability to integrate. The numerical usability score of 78.75 for the IVR service highlights its excellent usability, which is in line with the results of a similar study in Guinea [Wolfe, 2015]. However, it is important to note that speech recognition technology for African languages remains an under-researched area that requires further investigation. Initiatives such as Mozilla’s Common Voice Project¹³, which aims to create an open language database representative of different language communities, offer a promising way to democratise and diversify language technology for all.

5.4 Declaration of No Conflict of Interest

Our research did not involve any commercial agreements with the Viamo 3-2-1 service provider. Our sole interaction with them was to secure access to their platform for our study purposes. Every stage of the research process, including data collection and analysis, was carried out independently by our research team. It is important to note that our study received full funding from the University of Bordeaux.

5.5 Limitations

The proof of concept and its pretest exhibit several limitations. Firstly, the study was narrowly focused on high school students in Bobo Dioulasso, Burkina Faso, limiting the scope of its findings. Consequently, concerns arise regarding the applicability of these results to broader age groups or different geographical regions. Furthermore, a notable limitation lies in the insufficient availability of speech data necessary for the development of a voice interface in the Dioula language.

6 Implications of studies

The implications derived from two different case studies are promising in addressing health literacy challenges, especially in underserved communities. Study case 1, which looks at the effectiveness of an IVR service in local languages for malaria education, highlights the critical importance of a localised and multilingual approach to health interventions. This study

13. <https://commonvoice.mozilla.org/fr>

illustrates the transformative impact of providing basic health information in languages that resonate with the target population, as promoting health literacy requires providing information in languages that are familiar to the community.

In addition, Case Study 1 sheds light on the critical factors that influence the use of technology for health education, namely usability, safety, trust and ease of use. These findings highlight the need to develop interventions with a user-centred approach to build trust and promote uptake, particularly in populations facing health inequalities. In addition, the case study highlights the urgent need for health education initiatives in underserved communities given the observed health literacy gaps. Integrating technology-enabled solutions, such as those offered by the IVR service, is proving to be an effective means of disseminating accurate health information and bridging the health literacy disparities of marginalised populations.

The transition to study case 7, which explores the usability of an IVR service to improve low-literate people's COVID-19 literacy, offers valuable insights into improving health literacy, particularly in the context of pandemic information overload (infodemics). The study's focus on personalised learning through mobile and IVR services highlights the significant potential of technology to deliver tailored health information. It underlines the importance of developing technology solutions that are tailored to the different needs of different user groups.

In summary, both case studies highlight the enormous potential of technology-enabled interventions to promote health literacy and provide accurate health information. The lessons learned from these studies underscore the importance of tailored approaches, user-centred design and concerted efforts to address health inequities in underserved communities. In addition, it is imperative to recognise the challenges posed by limited resources for African languages such as Dioula, which hinder the integration of speech recognition systems into local languages. There is an urgent need for significant efforts to build language corpora in underrepresented languages to improve accessibility to health information and technology-enabled solutions for marginalised communities. These insights are invaluable for the development of effective health interventions and have the potential to significantly improve overall public health outcomes.

7 Conclusion

This chapter has explored in detail the intricacies of developing and implementing mobile health information services, with a focus on the particular needs and challenges of people with limited literacy skills in underserved communities. Throughout this comprehensive research, several important themes emerge, all of which play a critical role in developing effective and impactful health information solutions. The paramount importance of language accessibility becomes clear. It is emphasised that providing health information in the local language greatly improves both accessibility and comprehensibility.

In addition, the chapter highlights the importance of following user-centred design principles. It emphasises that successful health information services must be carefully tailored to the specific needs and preferences of the intended user group. Factors such as choice of language, literacy levels and cultural considerations need to be carefully weighed to create solutions that resonate authentically with the target group.

Moreover, the integration of engaging elements, particularly serious games, is proving to be an effective strategy to motivate behaviour change and enhance the overall learning experience, especially for younger users. Non-functional requirements, with a particular focus on usability, are also comprehensively addressed. It becomes clear that simplicity, clarity and efficiency in system design are key to ensuring that health information services remain effective and user-friendly. Equally important are considerations of data security, privacy, cultural sensitivity and affordability, as together these elements contribute to user trust and system accessibility.

The chapter provides real-world context through two compelling case studies that provide tangible examples of how technology-enabled interventions can bridge gaps in health literacy and facilitate access to critical health information. These case studies highlight the practical application of the principles discussed in this chapter.

The implications of these findings extend far beyond the pages of this chapter. They show the promise of technology-based interventions, particularly in the context of improving health literacy in underserved communities. The chapter highlights the need for a holistic approach and advocates for tailored solutions and user-centred design to effectively address health inequities.

Finally, the chapter includes a call to action calling for concerted efforts to develop language resources in underrepresented languages. This important step is seen as critical to ensuring equitable access to health information and technology-based solutions for marginalised populations. It is a clear call to create a health information ecosystem that leaves no one behind, regardless of their educational background, and ultimately promotes healthier lives for all.

In this chapter, we have identified user requirements and designed a mobile-based prototype for providing health information to low-literate people. Given the low availability of speech data, which is a challenge when developing voice-driven applications in the local language Dioula, we contribute to the creation of an annotated language dataset in Chapter 6 Data set and structure of a language model Language model for the Dioula language.

Chapter 6

Creating a speech dataset and building a speech Model for the Dioula Language

The contributions to this chapter have been discussed in the following publications:

Accepted for publication

I.Ouedraogo, B.M.J Some Z.C.O Keita, E.Nabaloum, F.Bationo, R.Benedikter, G. Diallo,. "Deploying a speech recognition model for under-resourced languages: a case study on dioula wake words 1, 2, 3, and 4". 7th International Conference on Natural Language Processing and Information Retrieval, ACM Digital Library. <https://doi.org/10.1145/3639233.3639345>

1 Introduction

The need to develop a speech-enabled mobile interface has become increasingly apparent recently, especially in the context of improving accessibility for people with limited literacy. This is particularly true in the area of health information dissemination, where the effective use of such interfaces can contribute significantly to improving overall health literacy. However, the creation of comprehensive annotated language datasets remains a major challenge, especially for languages with limited resources, such as Dioula.

This study seeks to address this critical gap by setting out on the task of creating an annotated language dataset and developing a specific language model explicitly tailored to the Dioula language. By creating a robust dataset and a dedicated language model, this research aims to promote the seamless and effective use of health information by people with limited literacy skills, thereby improving their overall health literacy.

The integration of the Dioula language, which is widely spoken in West Africa, into the field of voice-enabled technology has the potential to revolutionise the accessibility and use of health information. By enabling people to connect with health services and resources through voice-based interactions, this initiative seeks to empower underserved communities by providing them with the necessary tools and resources to make informed health-related decisions to improve their overall well-being.

Furthermore, the active participation of the Dioula-speaking community in the creation of datasets and the development of language models not only ensures the cultural and linguistic authenticity of the technology, but also fosters a sense of ownership and empowerment within the community. By encouraging collaborative participation and co-creation, this study aims to pave the way for sustainable and impactful interventions that meet the unique needs and preferences of the community, thereby improving the overall effectiveness and relevance of the voice-enabled mobile interface within the Dioula-speaking population.

2 Overview of Automatic Speech Recognition

ASR is an ever-evolving field of research aimed at enabling computer systems to comprehend and interpret human speech. Over the years, numerous techniques and approaches have been developed to enhance the accuracy and performance of speech recognition systems. This section reviews voice-to-text extraction methods and voice classification, focusing on relevant approaches for low-resource languages like Dioula.

ASR is a field continuously evolving to enable computers to understand human speech. It extensively reviews voice-to-text extraction techniques and voice classification, particularly focusing on their applicability to low-resource languages like Dioula. The ASR process, illustrated in Figure 6.1, involves extracting signal parameters, generating phonetic hypotheses through acoustic-phonetic decoding, and constraining them via lexical and syntactic modules, especially for continuous speech recognition with broad vocabularies. Acoustic modeling entails creating statistical representations for feature vectors derived from speech waveforms, employing various models like Hidden Markov Models (HMMs), neural networks, and more. This modeling also adapts feature vectors for noise resilience during recognition, termed phonetic modeling.

Language modeling estimates prior probabilities independently of the signal, involving traditional grammars with binary probabilities and stochastic models like n-grams that derive probabilistic relationships between word sequences from corpora. Historical advancements in ASR have focused on statistical frameworks, computational infrastructure, and knowledge representation. The transition to statistical methods, particularly HMM-based acoustic models, marked a significant milestone. Adaptation algorithms, computational enhancements, and extensive speech corpora have refined speech modeling, with ongoing progress in decoding strategies driving further advancements in the field.

2.1 Speech feature extraction techniques

Feature extraction in speech processing involves converting the speech waveform into a parametric representation, often referred to as front-end signal processing [Cornaz, 2003]. This transformation aims to create a more concise yet meaningful representation that is more discerning and dependable compared to the original signal. As the initial step in this sequence,

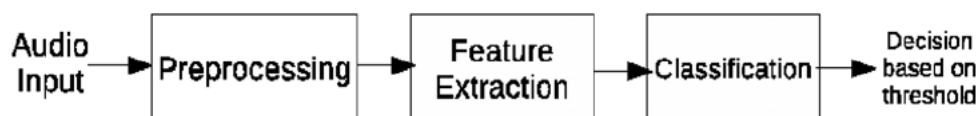


Figure 6.1 – Steps in Speaker Recognition [Joshy, 2016]

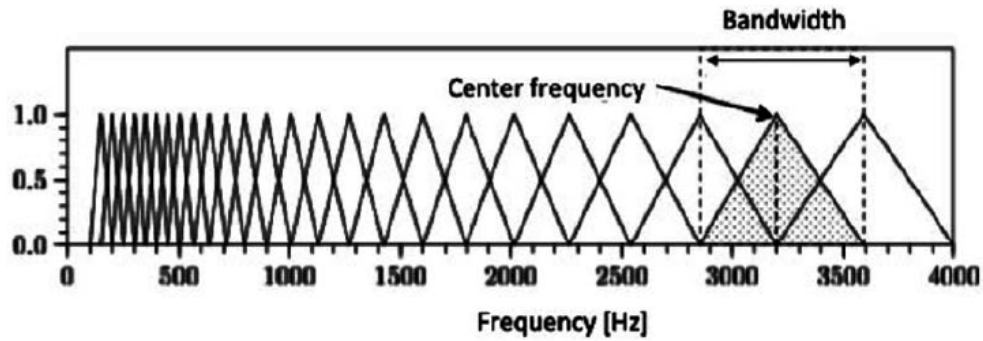


Figure 6.2 – Filterbank with 25 Triangular Bandpass Filters to Compute the Mel Frequency Spectrum [Joshy, 2016]

the quality of subsequent features, like pattern matching and speaker modeling, heavily relies on the quality of this front-end processing [Shah, 2009]. Hence, achieving accurate classification hinges significantly on obtaining superior-quality features.

In contemporary ASR systems, the objective of feature extraction is typically to find a representation that remains reliably consistent across diverse conditions of the same speech signal, even with variations in environmental factors or speakers, while preserving crucial information within the speech signal [Shrawankar, 2013]. These extraction methods typically produce multidimensional feature vectors for each speech signal [Alim, 2018]. Several options exist for parametrically representing speech signals during the recognition process, such as perceptual linear prediction (PLP), linear prediction coding (LPC), and mel-frequency cepstrum coefficients (MFCC). Among these options, MFCC stands out as the most widely recognized and popular approach [Alim, 2018].

2.1.1 Mel Frequency Cepstral Coefficients (MFCC)

MFCC is a widely used technique for extracting speaker recognition and verification features. It was initially introduced by Bridle and Brown in 1974 and further developed by Mermelstein in 1976 [Muda, 2010]. This method is based on the human hearing system, which is less sensitive to frequencies above 1 KHz. It utilizes two filters: one with linear spacing at frequencies below 1000 Hz and another with logarithmic spacing above 1000 Hz [Joshy, 2016]. The following steps involved in MFCC are illustrated in Figure 6.3.

Framing

Framing refers to the segmentation of the digitally converted input speech signal into smaller frames, typically lasting between 20 ms to 40 ms. These voice signals are divided into N frames, with adjacent frames separated by M (where $M < N$). Commonly employed values for M and N stand at $M=100$ and $N= 256$. [Muda, 2010].

Fast Fourier Transform The subsequent step involves converting the acquired voice samples from the time domain to the frequency domain. To accomplish this, the Fast Fourier Transform (FFT) is utilized. [Joshy, 2016].

$$c_{\tau,k} = \left| \frac{1}{N} \sum_{j=0}^{N-1} f(i) \exp \left[-i2\pi \frac{jk}{N} \right] \right| \quad k = 0, 1, \dots, (N/2) - 1 \quad (1)$$

where N is the number of sampling points within a speech frame and the time frame T .

Mel Scale Filtering

After the FFT, the resulting frequencies are broad, and voice signals do not adhere to a linear scale. To emulate the frequency ranges similar to those of normal human voice signals, the Mel Scale Filtering technique is implemented. This involves filtering the FFT-derived spectrum using N_d band-pass filters and subsequently calculating the power within each frequency band. This method mirrors the human auditory system's functioning, utilizing power across frequency bands for subsequent processing. This concept can be elucidated through the following equation [Joshy, 2016]:

$$c_{\tau,k} = \sum_{k=0}^{N/2-1} d_{j,k} c_{\tau,k}^{(1)} \quad j = 0, 1, 2, \dots, N_d \quad (2)$$

where d is the amplitude of the band-pass filter with the index j at the frequency k .

In Figure 6.2, a bank of Mel Scale filters is depicted, operating on the spectrum post-FFT. This visual representation showcases a collection of 25 triangular filters utilized to calculate a weighted sum of filter spectral components, aiming to align the output with the Mel scale. Each filter exhibits a triangular magnitude frequency response: it registers unity at the center frequency and gradually diminishes linearly to zero at the center frequency of two adjacent filters [Muda, 2010]. Following this process, the subsequent equation is utilized to compute the Mel value for a given frequency f in Hertz.

$$F(\text{mel}) = [2595 * \log_{10}[1 + f]/700] \quad (3)$$

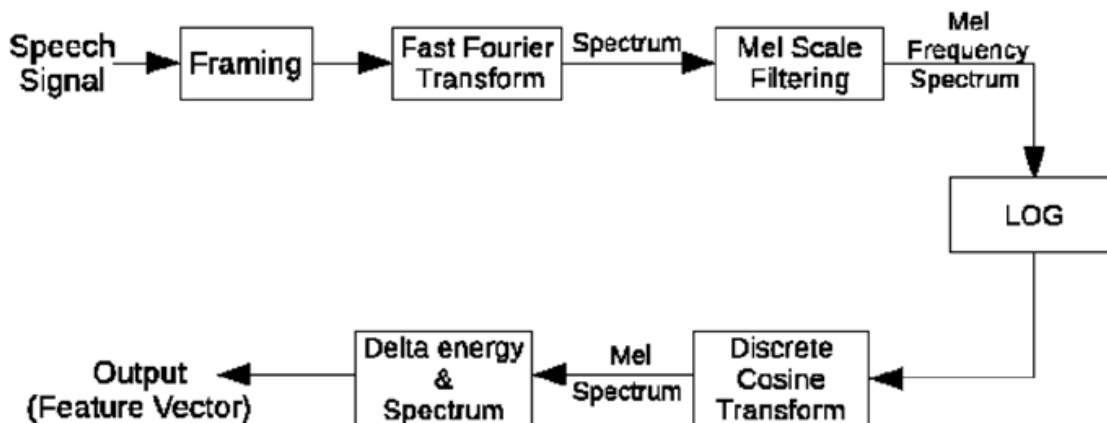


Figure 6.3 – Steps in MFCC [Joshy, 2016]

Logarithm Experiments have demonstrated that human perception of loudness follows a logarithmic scale. Consequently, to replicate this human perception of loudness, the logarithm of the signal is computed in this step [Joshy, 2016].

$$c_{r,k} = \log(c_{r,j}) \quad j = 0, 1, 2, \dots, N_d \quad (4)$$

Discrete Cosine Transform Following the acquisition of the logarithm of the Mel Spectrum in the preceding stage, the process involves transforming this log Mel Spectrum into the time domain. This transformation is accomplished using the Discrete Cosine Transform (DCT). The resulting conversion is referred to as **MFCC**. These sets of coefficients are recognized as acoustic vectors. Consequently, after this stage, each input utterance undergoes transformation into a set of acoustic vectors [Muda, 2010].

Delta Energy and Spectrum The voice signal and the frames undergo changes, such as the slope of a formant at its transitions. So it is needed to add features related to the change in cepstral features over time. 13 delta or velocity features (12 cepstral features plus energy), and 39 features a double delta or acceleration feature are added. The energy in a frame for a signal x in a window from time sample t_1 to time sample t_2 , is represented by the equation below:

$$\text{Energy} = \sum X^2[t] \quad (5)$$

Each of the 13 delta features represents the change between frames in the equation (6) corresponding to cepstral or energy feature, while each of the 39 double delta features represents the change between frames in the corresponding delta features [Muda, 2010].

$$d(t) = \frac{c(t+1) - c(t-1)}{2} \quad (6)$$

2.1.2 Other feature extraction approaches

Among other feature extraction methods used to parametrically represent speech signals during the recognition process include:

- **LPC** is an analysis technique which imitates the human vocal tract to provide robust vocal characteristics. It evaluates the speech signal by approximating formants and estimating the residual frequency. LPC is primarily used for formant estimation in a speech signal, enabling high-quality coding at low bit rates. It's utilized across various domains, including mobile robotics, tonal analysis of musical instruments, and telecommunication.
- **LPCC** derived from LPC, LPCCs are features obtained from the spectral envelope of LPCs. LPCCs, less correlated than LPCs, offer a more efficient representation of vocal characteristics. Cepstral analysis, commonly used in speech processing, compactly represents waveforms and vocal properties. LPC to LPCC conversion is feasible for signals with minimal phase.
- **LSF** LSFs, used in linear prediction analysis of voice, define two resonance situations of the human vocal tract. They are well-suited for speech coding, providing better quantification ability compared to other methods. LSF illustration reduces bit rate while preserving speech synthesis quality. Additionally, it's suitable for interpolation due to its diagonal sensitivity matrix.
- **DWT** analyzes signals, identifying high-frequency events with improved temporal resolution. Operating on variable scales in time and frequency domains, DWT efficiently represents non-stationary real signals. Discrete Wavelet Transform offers increased flexibility in decomposing signals into sub-bands, finding applications in signal processing to extract crucial information from transient signals in time and frequency.

- **PLP** combines features of human hearing, such as critical bands, sound intensity compression, and volume equalization, to extract relevant speech information. Aimed at eliminating speaker-specific traits, PLP provides a representation akin to MFCCs. It utilizes linear predictions for spectral smoothing, offering orthogonal outputs similar to cepstral analysis. PLP improves the quality and efficiency of extracting sound characteristics, used in speech recognition and speech analysis tasks.

	Type of Filter	Shape of filter	What is modeled	Speed of computation	Type of coefficient	Noise resistance	Sensitivity to quantization/additional noise	Reliability	Frequency captured
Mel frequency cepstral coefficient (MFCC)	Mel	Triangular	Human Auditory System	High	Cepstral	Medium	Medium	High	Low
Linear prediction coefficient (LPC)	Linear Prediction	Linear	Human Vocal Tract	High	Autocorrelation Coefficient	High	High	High	Low
Linear prediction cepstral coefficient (LPCC)	Linear Prediction	Linear	Human Vocal Tract	Medium	Cepstral	High	High	Medium	Low & Medium
Line spectral frequencies (LSF)	Linear Prediction	Linear	Human Vocal Tract	Medium	Spectral	High	High	Medium	Low & Medium
Discrete wavelet transform (DWT)	Lowpass & high pass	—	—	High	Wavelets	Medium	Medium	Medium	Low & High
Perceptual linear prediction (PLP)	Bark	Trapezoidal	Human Auditory System	Medium	Cepstral & Autocorrelation	Medium	Medium	Medium	Low & Medium

Table 6.1 – Comparison between the feature extraction techniques [Alim, 2018]

Table 6.1 presents a comparative analysis of the six explicitly described feature extraction techniques. While the choice of a feature extraction algorithm can vary based on individual needs, this table effectively outlines these techniques according to key selection criteria for any feature extraction method. These criteria encompass computation speed, noise resistance, and sensitivity to additional noise. Additionally, the table serves as a valuable reference for evaluating and choosing between the discussed algorithms in research applications.

2.2 Speech classification techniques

In the domain of speech classification, various tasks involve automatically categorizing spoken utterances or audio segments into distinct classes. These tasks encompass speech recognition for vocal commands (multi-class), voice activity detection (binary or multi-class), and audio sentiment classification (typically multi-class), among others.

- **Vocal Command Recognition** Vocal command recognition involves classifying input audio patterns into discrete classes [Bala, 2010]. It falls under *ASR*, sometimes referred to as "Keyword Spotting," where models continuously analyze speech patterns to detect specific "commands." These models aim to be compact and efficient, facilitating deployment on low-power sensors for extended periods. Practical applications include voice control for electronic devices, personal assistants, and home automation systems.
- **Voice Activity Detection (VAD)** Voice Activity Detection predicts which parts of input audio contain speech against background noise [Ramirez, 2007]. It plays a crucial role in speech-based applications, aiding in determining relevant audio portions for the speech recognition model. VAD estimates noise statistics and removes non-speech periods, reducing insertion errors caused by noise in training/testing conditions. This technique, often employing Fourier coefficients, periodicity, and zero-crossing rates, utilizes statistical models like Gaussian or Laplacian distributions to distinguish speech from noise.
- **Spoken Language Identification (Lang ID)** Spoken Language Identification automatically recognizes the language in a speech sample, serving as a crucial preprocessing step for *ASR* [Abdullah, 2020b]. It directs the input flow to the appropriate *ASR* model based on the detected language, thereby enhancing overall speech processing accuracy and

efficiency. The identification process involves two phases [Zissman, 2001]: training, where speech waveforms create language-specific models, and recognition, where new speech samples are compared to these models to determine the spoken language. These techniques—vocal command recognition, voice activity detection, and spoken language identification—play pivotal roles in the realm of automatic speech processing, contributing to enhanced accuracy and efficiency in speech-related applications.

3 Speech recognition for under-resourced languages

Speech recognition for underserved languages is a critical aspect of bridging information gaps and improving access to critical services, especially in underserved communities. Local languages are often the primary means of communication in these areas, and developing technologies that support these languages can have a profound impact. Speech recognition technology is a powerful tool for people with low literacy skills, as it allows them to interact with systems using their voice. By developing speech recognition systems that support local languages, we can effectively address literacy and language barriers that often hinder access to important services, including health care. In the area of health information dissemination, for example, AI-powered speech recognition can enable people to access medical advice and important health information in their native language, improving their understanding and engagement with health resources. In addition, local languages are of great cultural importance in underserved communities. Incorporating these languages into technological solutions such as speech recognition systems demonstrates a commitment to cultural diversity and inclusion. It fosters a sense of identity and belonging among community members, which can contribute significantly to the acceptance and effectiveness of these systems.

The importance of local languages and speech recognition goes beyond providing information; it also empowers individuals, promotes health literacy and enables better communication between health providers and community members. By removing language barriers through the development of speech recognition systems, technology can play a critical role in improving the overall well-being and quality of life of underserved populations.

To make speech recognition systems effective for local languages, it is important to create annotated language datasets tailored to these specific languages. These datasets serve as the basis for training and improving the accuracy of speech recognition models, ensuring that these systems are not only inclusive but also meet the specific needs of underserved communities.

4 Technical approaches for under-resourced languages

The automatic processing of speech in under-resourced languages faces a fundamental challenge: the scarcity of linguistic data. Magueresse et al [Magueresse, 2020] proposed two approaches to address this issue: creating new datasets by annotating raw text and aligning raw text with a language that boasts richer resources. When applied to the specific domain of automatic speech processing, these strategies involve annotating new raw audio recordings or aligning these recordings with a language possessing more abundant linguistic resources. Additionally, studies such as [Gales, 2014; Hinton, 2012; Seide, 2011], highlight that leveraging deep neural networks (DNNs) yields significant performance gains for speech recognition systems with limited resources. Transfer learning and data augmentation techniques were also proposed to address the scarcity of data:

- **Transfer learning** is a promising approach to tackle data scarcity in under-resourced languages is transfer learning, as suggested by [Karunanayake, 2019]. This method involves harnessing knowledge obtained from a well-resourced language to develop automatic speech-processing systems in a less-resourced language. Rather than building a model from scratch, transfer learning utilizes a pre-trained model from the source language and adapts it to the target language. This approach saves time and resources by circumventing the need for extensive data collection and annotation for the target language, thereby enhancing the accessibility of speech-processing technologies worldwide.
- **Data augmentation** serves as a relevant strategy to enhance the performance of automatic speech processing models in under-resourced languages [Ragni, 2014; Li, 2020]. This method involves artificially generating new data from existing data. Various techniques, including varying speech speed, changing tone, adding noise, or synthesizing speech, contribute to increasing the variety and diversity of training data. However, ensuring that the generated data remains representative of the target language is crucial to avoid a degradation in model quality.

5 Related works

Africa's linguistic diversity, comprising over 2,000 languages, presents a unique challenge to the existing NLP ecosystem [Margani, 2023]. Unfortunately, these languages are often underrepresented and lack essential digital resources needed for effective engagement in advanced language technologies. Bridging this gap has attracted a great deal of attention from

researchers and organisations and has led to various initiatives aimed at strengthening African languages and transferring NLP methodologies to these diverse linguistic landscapes. One notable community-driven initiative, Masakhane, has played a crucial role in advancing NLP research in Africa through a participatory approach to community building [Orife, 2020]. Masakhane's collaborative efforts have fostered a sense of common purpose among researchers, practitioners and language enthusiasts, leading to the development of valuable resources and models for African languages. The establishment of the Lacuna Fund has further accelerated progress in this area. This fund provides critical support to African researchers and organisations to create open-access text and language resources for NLP research¹. This support has been instrumental in initiating data collection and resource development, especially for LRL's.

The AI4D - African Language Programme represents an important milestone in addressing the resource gap for African languages [Siminyu, 2021]. This programme focuses on collecting and curating language datasets, such as the English-Luganda Parallel Text Corpus ([Mukiibi, 2021]. These resources not only facilitate NLP research, but are also suitable for domain-specific applications. Efforts to create and curate datasets go beyond language- and domain-specific collections. For example, the work of Vukosi et al. [Marivate, 2020] led to the creation of datasets for news headlines in two low-resource South African languages, Setswana and Sepedi. These datasets, organised by different topics, are valuable tools for text classification and information retrieval tasks.

In the area of language data, initiatives have used platforms such as Mozilla's Common Voice² to create freely available language datasets. Kinyarwanda was the first African language to be launched on this platform and has an extensive collection of recorded and validated speech data (Mozilla Common Voice). Other African languages, including Luganda, Swahili and Igbo, have also found their way onto the platform through community mobilisation. The multifaceted approach to resource development also extends to mobile applications, as demonstrated by David et al. [Blachon, 2016], who developed an application to collect parallel voice data for underserved languages such as Mboshi, Myene and Basaa.

The joint initiatives of Masakhane, the Lacuna Fund, AI4D - African Language Programme and contributors to Mozilla's Common Voice platform are instrumental in addressing the lack of digital resources for underserved African languages. These initiatives not only promote the development of language datasets but also facilitate the implementation of language interfaces and digital health resources in local languages. They are critical in improving access to and use of digital health solutions, especially in promoting access to health information in low-literacy populations.

6 Building a database and speech recognition model for wake words 1,2,3 and 4 : case study 8)

In today's technological landscape, ensuring equal access is not just a luxury, but a fundamental right. However, this access is often denied to underserved languages, with African languages such as Dioula facing bottlenecks in digital resources. This section describes an initiative that aims to create a database and develop a speech recognition model that focuses specifically on wake words 1, 2, 3 and 4 in Dioula. The context emphasises the digital challenges faced by Dioula and positions this study as a proactive step to address the digital inequalities faced by this language community. The subsequent investigation takes us through the intricacies of model development, and the central role of data augmentation, with the aim of highlighting the Dioula language in the evolving landscape of language technologies. The provision of a language dataset plays a crucial role in the development of mobile health information that is accessible to people with low literacy skills.

6.1 Context

In today's interconnected world, equitable access to technology is no longer just a luxury but a fundamental right [Gabardo, 2022]. Unfortunately, underserved languages, particularly African languages like Dioula, often lack the digital resources necessary for full participation in the evolving landscape of language technologies [Babirye, 2022]. This digital divide places speakers of these languages at a distinct disadvantage. According to Krauwer [Krauwer, 2003] and Berment [Berment, 2004], such underserved languages commonly lack standardized writing systems, have limited online presence, suffer from a scarcity of linguistic expertise, and are deficient in electronic resources for language and speech processing. Dioula, a Western Mande language spoken in Burkina Faso, Ivory Coast, and Mali by approximately 12.5 million people³, encounters significant obstacles due to the dearth of linguistic resources. Despite its cultural significance and widespread usage, Dioula lacks the necessary quantity and quality of linguistic materials crucial for technological advancements, particularly in the domain ASR systems. This scarcity significantly limits the Dioula-speaking community's access to vital services and information. Currently, to the best of

1. <https://lacunafund.org/datasets/language/>

2. <https://commonvoice.mozilla.org/fr/languages>

3. <https://omniglot.com/writing/dioula.htm>

our knowledge, there are no existing corpora or datasets suitable for training a speech recognition model for Dioula. Nonetheless, certain studies have addressed similar challenges for related languages such as Bambara. In 2014, Maslinsky developed the Daba software, designed for corpus development for Manding languages, including Bambara [Mangeot, 2014]. In 2020, Tapo et al. [Tapo, 2020] conducted research on neural machine learning translation for resource-scarce African languages, with a specific focus on Bambara. Additionally, in the same year, Maslinsky made notable contributions by creating a linguistically rich n-gram frequency dataset for Bambara [Maslinsky, 2019].

This research aims to bridge the digital divide for under-resourced languages, particularly Dioula, by constructing a Dioula voice recognition model capable of recognizing spoken numerals 1, 2, 3, and 4 in the Dioula language. To support this initiative, we have developed the Dioula speech dataset for wake words 1, 2, 3, and 4, with the intent of facilitating research in NLP, machine learning, translation, and linguistic analysis.

In the context of enhancing our IVR service, we envision integrating this trained model for recognizing the numbers 1, 2, 3, and 4 into our interactive voice server. This integration will facilitate smoother navigation for low-literate users through voice-based menus in the local Dioula language. As a result, users will be able to access crucial health information without the requirement of advanced numeracy skills.

6.2 Methods and materials

6.2.1 Data Collection

Successful speech recognition systems hinge on high-quality, well-prepared data, a critical factor when dealing with under-resourced languages like Dioula. Our data collection process involved the following key steps.

- Objective Definition and Consent: Before data collection, we clearly defined our objectives, focusing on recognizing Dioula numbers 1, 2, 3, and 4. We ensured that speakers understood the importance and intended use of their voice recordings, obtaining their consent.
- Recording Environment: Voice recordings can significantly vary based on the environment. To capture natural speech, we recorded in both studio settings and natural environments, balancing controlled conditions with real-world scenarios.
- Data collection: we sent out a form through WhatsApp to Dioula native speakers to collect data from March to June 2023. Jotform data collection form in Appendice 2 figure 1, an online platform for creating and managing forms, played a crucial role in facilitating data collection. This web-based solution enabled the convenient submission of voice recordings remotely. The data collected served as wake words 1, 2, 3 and 4 speech datasets.
- Addressing data collection challenges: Collecting data for under-resourced languages presented challenges. Initial engagement was limited, so we initiated a second data collection phase, directly obtaining data from speakers to bolster our dataset.

The collected vocal data is accessible on Zenodo⁴. This dataset is a valuable resource for researchers and developers interested in Dioula speech recognition and related technologies.

6.2.2 Data preparation and pre-processing

The preparation and pre-processing of the audio data involved several essential steps to ensure the quality and suitability of the data set for model development. Transcription was a crucial step to prepare the speech data for training. Each voice recording was meticulously linked to a corresponding text, with Jotform facilitating this process.

- Data verification: first, we checked the correctness of the collected recordings in terms of their expected classes, especially numbers 1, 2, 3 and 4 in Dioula. This step was crucial to ensure the accuracy and reliability of the dataset. We did not want to rely solely on users' interpretations, as we knew that users might say something different from the requested numbers or remain silent. Therefore, we removed all unnecessary files to maintain data integrity.
- Format conversion: To ensure compatibility with subsequent processing steps, we converted all voice recordings to the commonly accepted WAV format. This conversion facilitated seamless integration with Python's audio processing libraries.
- Voice activity detection: Another important pre-processing step was the application of a voice activity detection procedure. This procedure effectively eliminated silence phases and noise that occurred before and after the speech segments in the audio recordings. The aim was to improve the overall quality of the data set by focusing on the vocal content.

4. <https://doi.org/10.5281/zenodo.8320370>

6. Building a database and speech recognition model for wake words 1,2,3 and 4 : case study 8)

- Creating a balanced dataset: Creating a balanced dataset was paramount to training an unbiased and robust model. We took great care to ensure that each target class had an approximately equal number of samples, namely 425 audio samples per class, so that we have a total of 1,700 audio samples (296.3MB corresponding to around 1.4 hour) evenly distributed across the four classes (numbers 1, 2, 3 and 4 in Dioula), as shown in 6.4.

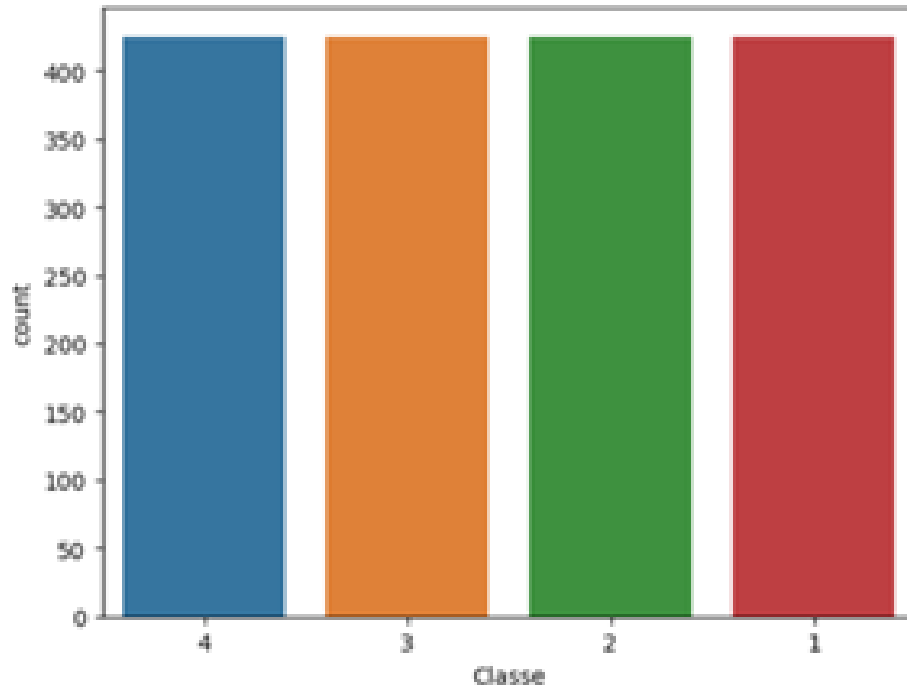


Figure 6.4 – Data overview by class

	Audio	Classe
0	./AudiosNormalises copie/Classe_4/63fe62464753...	4
1	./AudiosNormalises copie/Classe_4/63fe5fe411c7...	4
2	./AudiosNormalises copie/Classe_4/64789332e949...	4
3	./AudiosNormalises copie/Classe_4/6473193a925e...	4
4	./AudiosNormalises copie/Classe_4/647458648e7f...	4
...
1695	./AudiosNormalises copie/Classe_1/6479dd8a895b...	1
1696	./AudiosNormalises copie/Classe_1/6479dd19d0ff...	1
1697	./AudiosNormalises copie/Classe_1/6476598788b6...	1
1698	./AudiosNormalises copie/Classe_1/64750b66e339...	1
1699	./AudiosNormalises copie/Classe_1/647765f5218b...	1

1700 rows × 2 columns

Figure 6.5 – Overview of the data sets

These audio samples were stored in a DataFrame, as shown in F6.5. The DataFrame contained 1,700 rows, each row representing a single audio sample. The "Audio" column contained the file path to each audio file, while the "Class" column indicated the Dioula number pronounced in each audio. We also presented waveform images of representative audio samples for each of our four classes, as shown below in Figures 6.6, 6.7, 6.8 and 6.9.

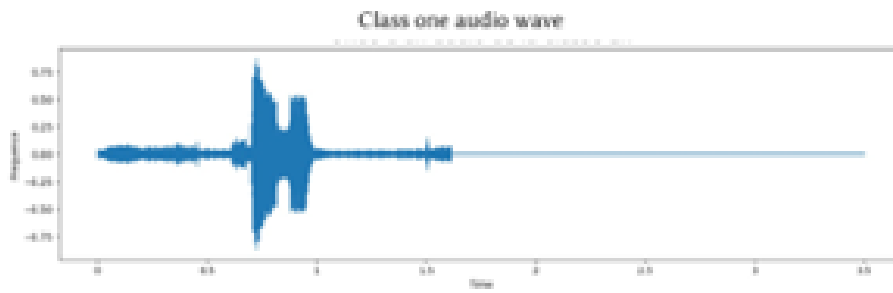


Figure 6.6 – Wave image of "1" pronounced in Dioula

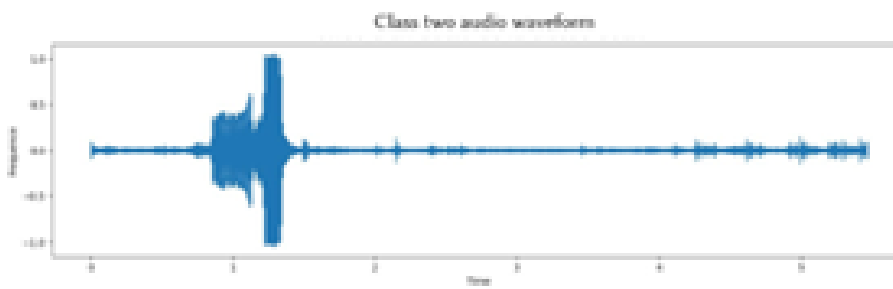


Figure 6.7 – Wave image of "2" pronounced in Dioula.

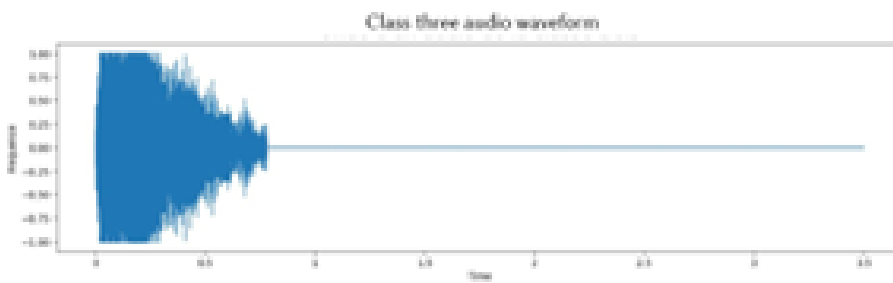


Figure 6.8 – Wave image of "3" pronounced in Dioula.

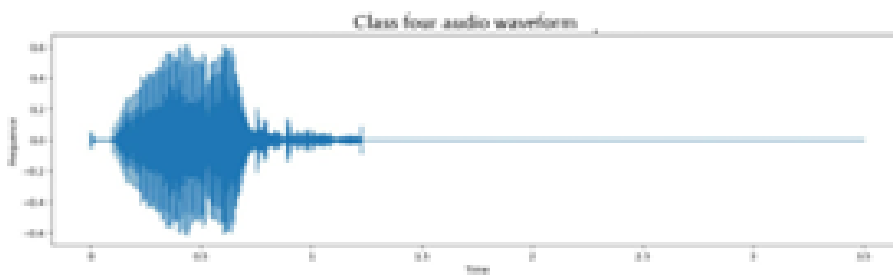


Figure 6.9 – Wave image of "4" pronounced in Dioula.

To meet the data requirements of a model of this size, we performed a series of processing steps to expand the data, as described earlier. This expansion process significantly increased the size of the data set, giving us a total of 35,700 audio samples, with 8,925 audio samples per class (number). In summary, the careful data preparation and pre-processing steps ensured the quality of the data set and its suitability for model development. This provided a solid foundation for the subsequent modelling and recognition tasks.

6.2.3 Feature Extraction (MFCC)

Feature extraction was paramount, and Mel Frequency Cepstral Coefficients (MFCCs) played a central role. Their advantages include compatibility with human perception, dimensionality reduction, robustness, discriminative features, and adaptability to various languages.

6.2.4 Modeling and Model Training

Developing a model for Dioula speech recognition required considering the unique challenges of under-resourced languages. As shown in 6.10 the model comprised the following key components:

- Microphone: Responsible for recording audio data containing Dioula numbers 1, 2, 3, or 4, serving as the system's input source.
- Preprocessing and Feature Extraction Phase: This phase cleaned and extracted vital frequency features from recorded audio data, ensuring proper formatting.
- Neural Network Architecture: Deep learning techniques powered the model, allowing it to learn complex patterns from data efficiently.
- Activation Function: We used the 'tanh' activation function to convert network outputs into probabilities, crucial for classification.

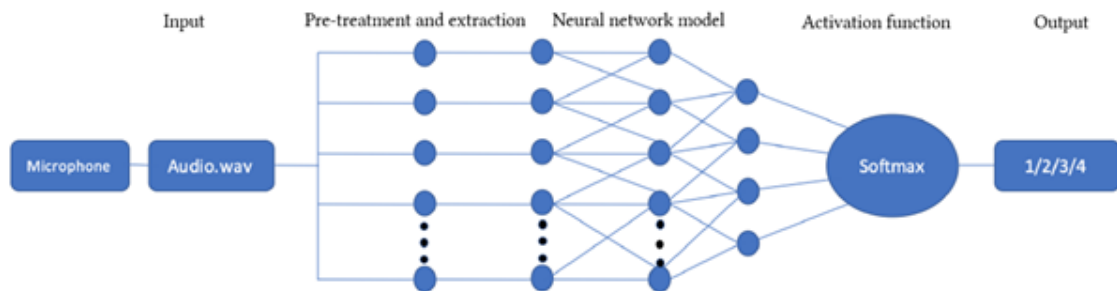


Figure 6.10 – General architecture of the system

6.2.5 Rationale for model architecture

We have chosen a neural network to model the recognition of the digits 1, 2, 3 and 4 pronounced in Dioula. This architecture is shown in 6.11 below. This is the result of a search for the hyperparameters of the model. The search for the hyperparameters was done using the KerasTuner library [Team, 2022]. We used the Hyperband class [Li, 2017], which implements the algorithm of the same name. This algorithm focuses on speeding up the random search through adaptive resource allocation and early stopping. Our choice of model architecture was grounded in critical considerations.

- Machine Learning Capability: Neural networks autonomously learn from data, ideal for recognizing complex audio patterns.
- Complex Feature Extraction: Deep architectures excel at extracting intricate features from data, vital for speech recognition.
- Sequence Processing Capability: Bidirectional LSTM layers enable the model to process sequential data effectively.
- Adaptability to Languages and Accents: Neural networks generalize from training data, crucial for LRL's.
- Hierarchical Representation: Deep layers capture information at varying levels of abstraction. The final architecture resulted from hyperparameter tuning using KerasTuner's Hyperband algorithm, optimizing parameters like activation function, neurons per layer, dropout, regularization, optimizer, and epochs.

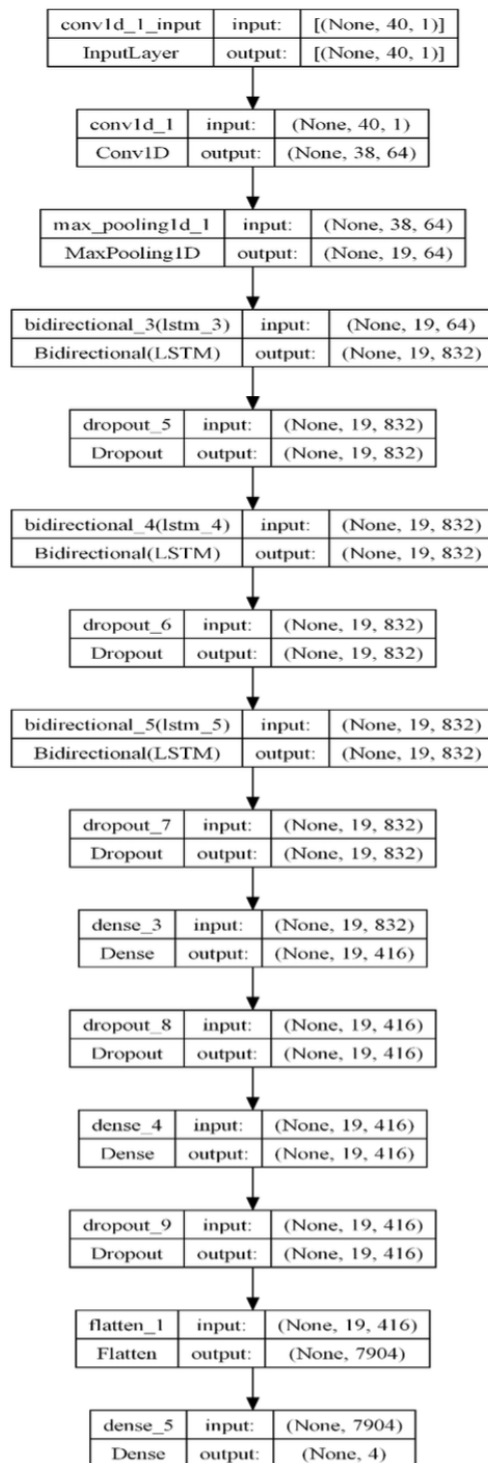


Figure 6.11 – Neural network architecture

6.2.6 Training the Number Classification Model (1, 2, 3, and 4)

Training our Dioula speech recognition model was a multi-layered process that involved several key components. The hardware on which the training took place played a crucial role in the successful development of the model. We used a laptop equipped with 32 GB RAM, an Intel® Core™ i7 processor and a dedicated NVIDIA Quadro M2000M graphics processor with extensive resources.

In terms of software, Python was the programming language. In particular, we used TensorFlow, a well-known deep learning framework, to facilitate the development and training of our speech recognition model. TensorFlow's capabilities were well suited to the intricacies of our task and allowed us to use deep learning techniques effectively. Tuning the hyperparameters was a crucial stage in refining our model for optimal performance. This careful process led to a targeted selection of critical hyperparameters. For the activation function, we chose 'tanh' to improve the performance of the model and promote efficient learning. The architecture of the model consists of 416 neurons per layer, a carefully chosen number that balances complexity and effectiveness.

To prevent overfitting and improve the generalisation capabilities of the model, we introduced a dropout value of 0.3. In addition, we used an L2 regularisation value of 0.001 to further improve the robustness of the model. The optimiser 'Adam' was chosen for its effectiveness in optimising the weights and biases of the model, which contributes to faster convergence during training.

The training process spanned a total of 80 epochs, ensuring that the model had sufficient exposure to the training data. This allowed the model to learn the intricate patterns and features of the Dioula language. This careful selection and hyperparameter tuning shaped our Dioula speech recognition model and enabled it to achieve the desired accuracy and efficiency in recognising the spoken numbers 1, 2, 3 and 4 in the Dioula language.

6.2.7 Significance of data augmentation

Data augmentation played a significant role in improving the performance of our Dioula speech recognition model. Augmentation involves artificially creating variations in the training data by applying transformations such as pitch shifting, time stretching, and noise addition. This technique helps the model generalize better and become more robust to real-world variations in speech. In our case, data augmentation addressed the challenge of limited data availability for Dioula. By generating additional training samples with augmented data, we increased the model's exposure to diverse speech patterns and variations.

This ultimately led to a substantial improvement in accuracy and reduced overfitting. Hyperparameter tuning, coupled with the use of data augmentation, significantly enhanced its performance. The evaluation metrics allowed us to assess the model's effectiveness in recognizing numbers 1, 2, 3, and 4 pronounced in Dioula. These components together formed the foundation of a robust and accurate speech recognition system for the Dioula linguistic community.

6.2.8 Technologies and frameworks used.

In terms of the technologies and frameworks used to implement our Dioula speech recognition system, we took a comprehensive approach to create a functional and user-friendly solution. The programming languages used included HTML5 for defining the page structure, CSS3 for layout management, JavaScript for interactivity and AJAX for asynchronous communication with the backend in the frontend (user interface). On the backend side (server), Python was chosen for its robustness and suitability for professional development, allowing seamless interaction with the machine learning model, which was also developed with Python libraries.

Frameworks played an important role. Bootstrap was used for the frontend to enable responsive and user-friendly web interfaces, while Django served as our backend framework, known for its ease of use, integration with Python, robust handling of HTTP requests and built-in security features.

For data persistence, we used the PostgreSQL database management system (DBMS). Object-relational mapping (ORM) helped to simplify the interaction between application classes and database tables. In addition, our system followed the Model-Template-View (MTV) architecture, a variant of the Model-View-Controller (MVC) architecture.

6.2.9 Performance evaluation metrics

The evaluation process was conducted with the active participation of 17 native speakers from Bobo Dioula, comprising 6 men and 11 women. This diverse inclusion of voices and genders contributed greatly to the authenticity and relevance of the evaluation. In the field of speech recognition, it is essential to use a set of metrics to thoroughly evaluate the performance of the model. These metrics provide important insights into the efficiency of the model in decoding and transcribing spoken commands. One of the most important evaluation tools we have used is the confusion matrix 6.2. This matrix provides a visual representation showing the predictions of the model alongside the actual class labels.

Table 6.2 – Confusion matrix for 4 classes

	Actual classes				
		A	B	C	D
Predicted classes	A	TP(A)	FP(A)	FP(A)	FP(A)
	B	FN(B)	TP(B)	FN(B)	FN(B)
	C	FN(C)	FN(C)	TP(C)	FN(C)
	D	FN(D)	FN(D)	FN(D)	TP(D)

Accuracy, another important metric, serves as a comprehensive measure of the overall performance of the model. It quantifies the model's ability to identify speech commands by calculating the proportion of correctly classified samples relative to the total number of samples. However, care must be taken when interpreting accuracy, especially in scenarios with an unbalanced class distribution, where it can occasionally be misleading.

Loss, another important metric, is used to quantify the deviation between the model's predictions and the actual values during the training phase. The main goal during training is to minimise this loss and thus reduce the gap between the model's predictions and the true values. After training, monitoring the loss in test data remains critical for performance evaluation. Visualising loss reduction across training epochs provides insight into how effectively the model is adapting to the data. It is important to strike a balance to avoid overfitting, where an overly complex model fits the training data too closely, resulting in lower validation or test loss.

In this representation:

- Cells on the diagonal represent True Positives (TP) for each class.
- Cells off the diagonal represent false Positives (FP) and False Negatives (FN) for each class combination.
- TP: True Positives for a class (real samples of the class correctly predicted as belonging to that class).
- FP: False Positives for a class (samples predicted in the class that do not belong to that class).
- FN: False Negatives for a class (real samples of the class incorrectly classified in another class).

6.3 Results

6.3.1 Confusion Matrices

Confusion matrices visually represent the model's performance by comparing its predictions to the actual class labels. The matrix in 6.12 reveals generally poor predictions for all the numbers. Only the number "1" stands out slightly, with 59 correctly predicted elements out of a total of 88 audio recordings.

The matrix in Figure 6.13 below suggests that, despite some incorrect predictions, the vast majority of numbers were correctly identified by our model. For example, for the number 1, 1762 recordings were correctly recognized out of a total of 1817, with 34 confused with the number 2, 2 with the number 3, and 19 with the number 4. A similar trend is observed for the numbers 2,3 and 4.

6.3.2 Accuracy

Accuracy measures how well our model recognizes speech commands overall. We observed two levels of accuracy:

- For the initial data: The accuracy was 51%, indicating that the model's performance on the unaltered dataset was relatively low 6.14.
- For augmented data: After applying data augmentation, the accuracy significantly improved to 96%, highlighting the substantial impact of data augmentation on model performance 6.15.

6.3.3 Loss

We noted the following levels of loss:

- For the initial data: The loss was 205%, indicating a high divergence between predictions and actual values, which is undesirable 6.16.

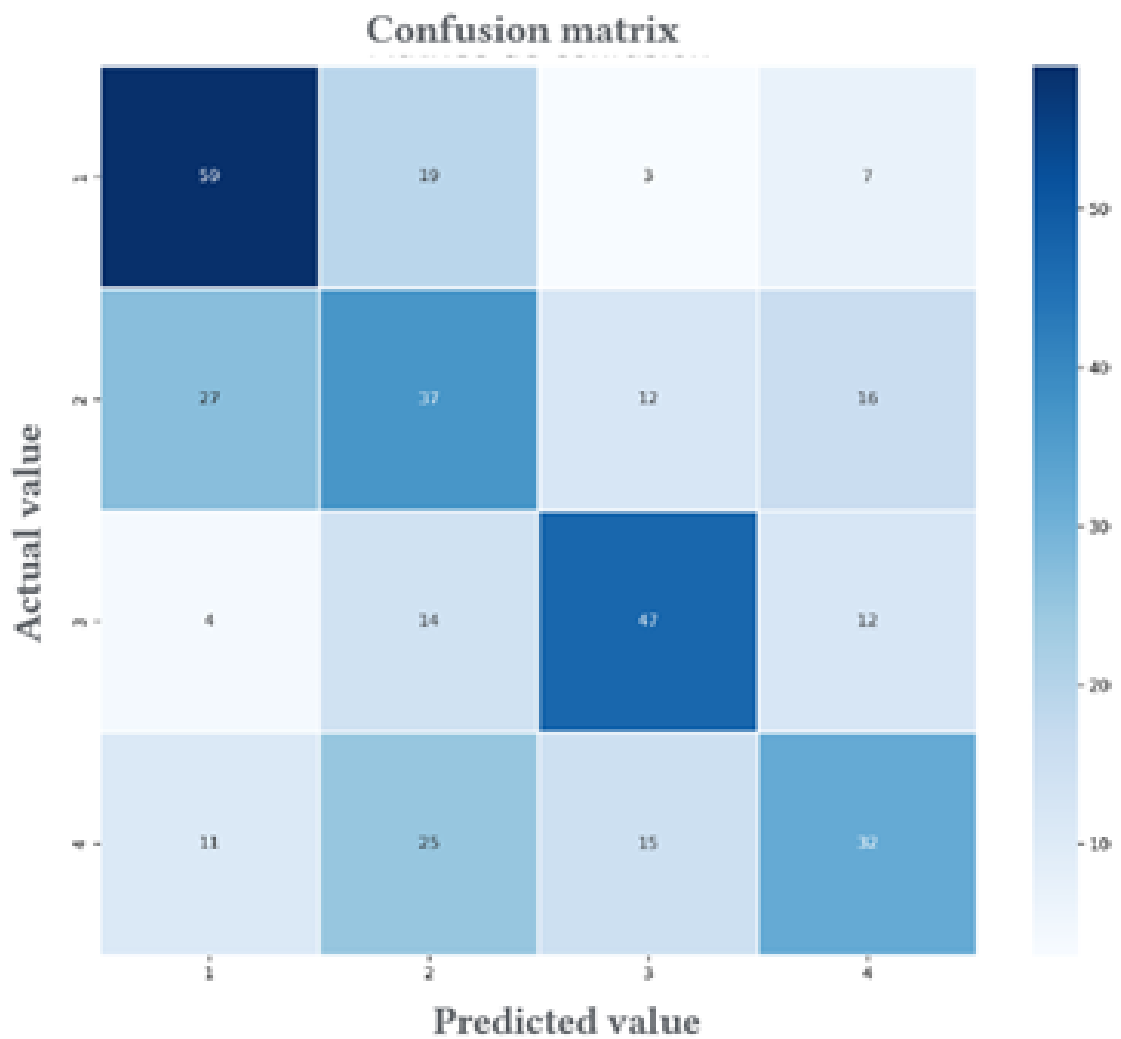


Figure 6.12 – Confusion matrix on the initial data: This matrix revealed generally poor predictions for all numbers, with only the number 1 demonstrating relatively better performance.

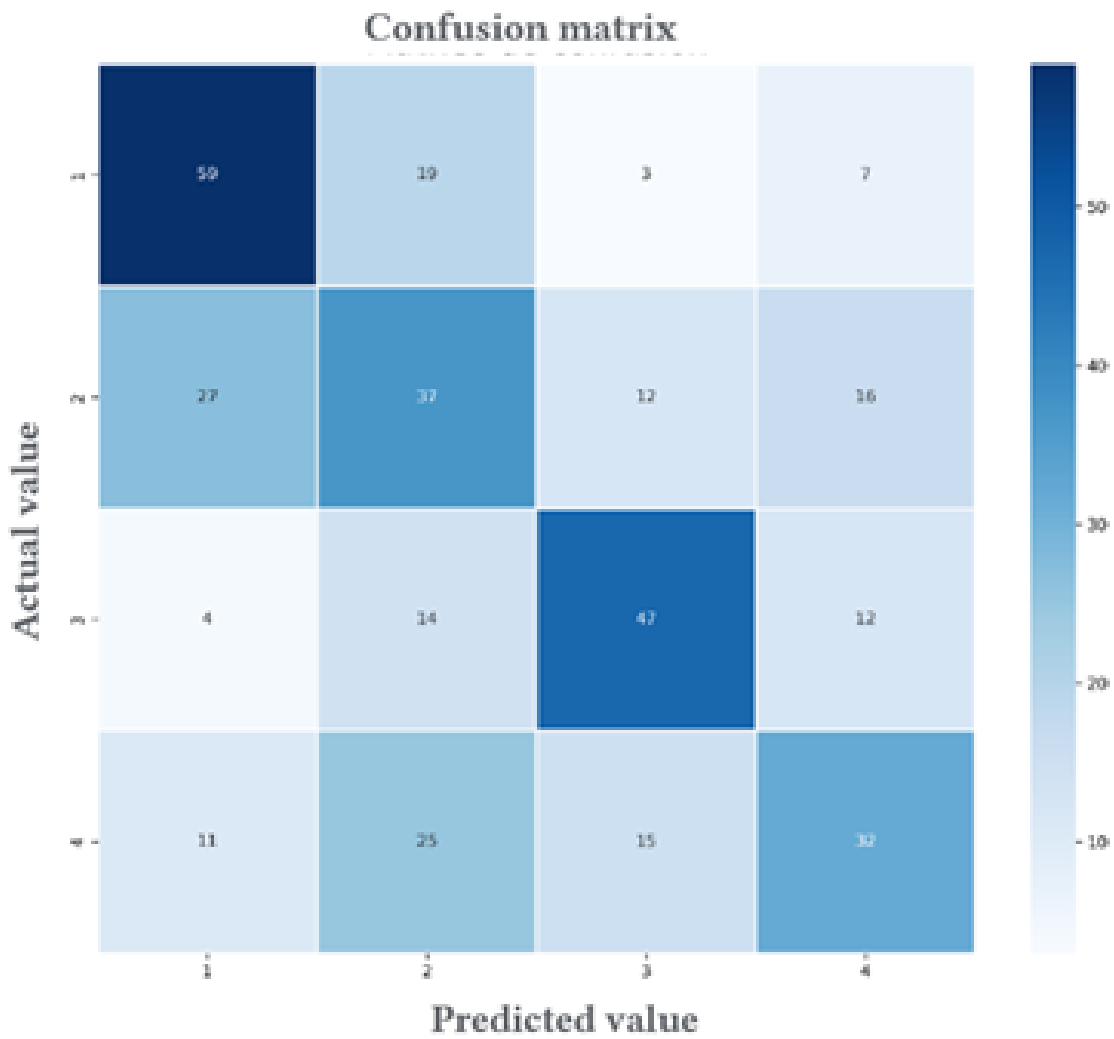


Figure 6.13 – Confusion matrix on augmented data: In contrast to the initial data, most numbers were well predicted by our model after data augmentation. For example, the number 1 was well-recognized in most cases.

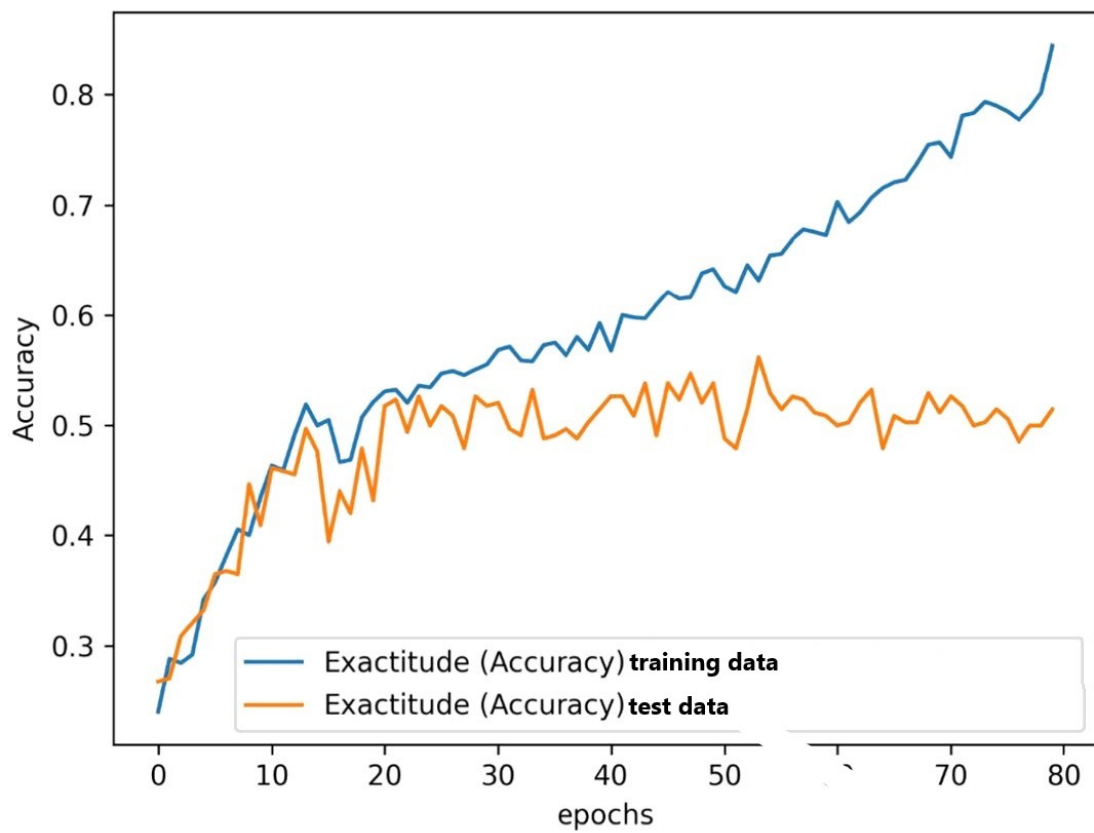


Figure 6.14 – Learning curve based on accuracy with initial data

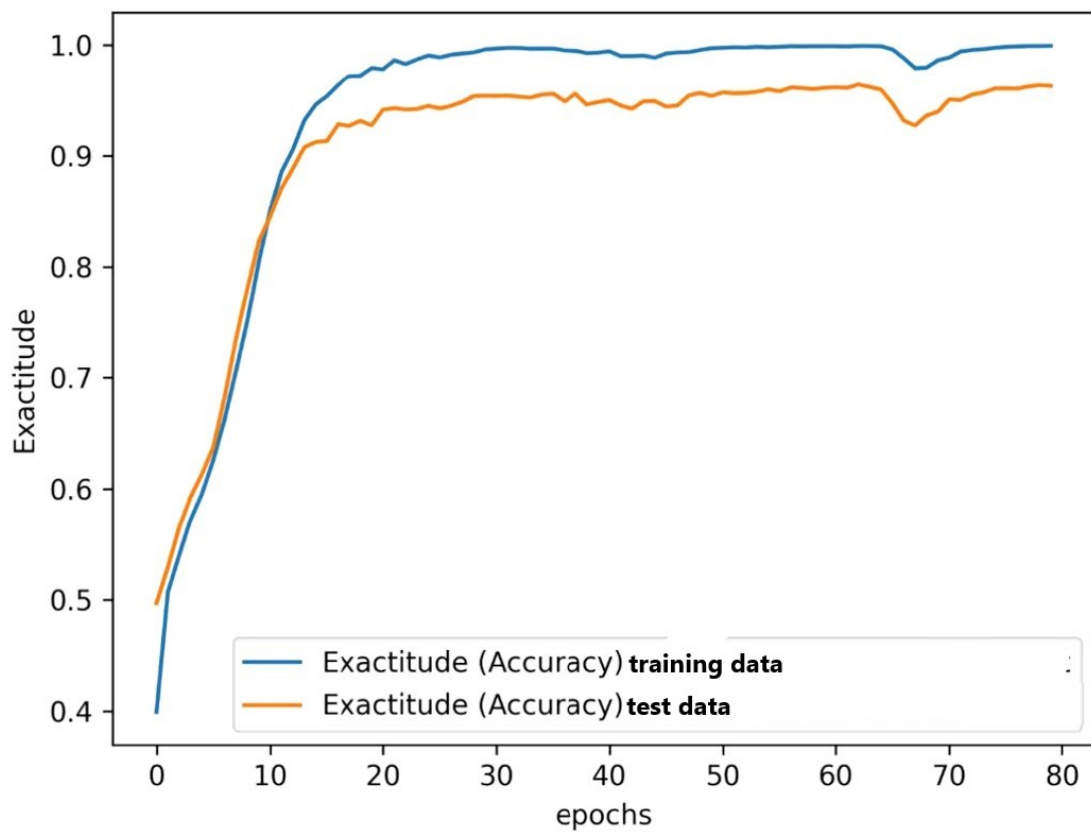


Figure 6.15 – Learning curve based on accuracy with augmented data

- For augmented data: After data augmentation, the loss decreased to 14%, reflecting a substantial improvement in model performance and its ability to fit the data 6.17.

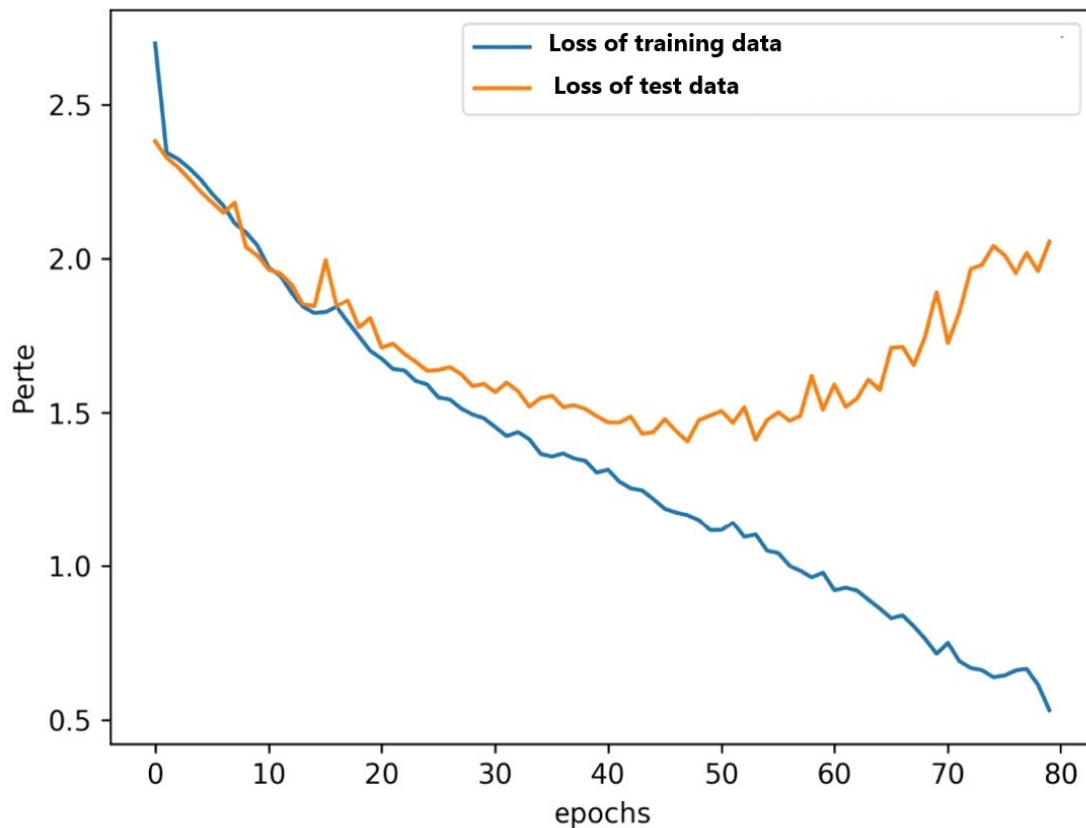


Figure 6.16 – Learning curve based on loss with initial data

6.4 Findings

The study highlights the challenge of limited training data for Dioula speech recognition, especially for the numbers 1,2,3 and 4 which is a significant obstacle to developing effective speech recognition models for resource-poor languages like Dioula. However, the research demonstrates the remarkable effectiveness of data augmentation techniques in overcoming data scarcity, resulting in a significant improvement in model accuracy, which increased from the original 51% to an impressive 96%. This result highlights the central role of data augmentation in improving the performance of speech recognition models. The evaluation of the Dioula speech recognition model initially showed below-average results, particularly in the recognition of Dioula numbers. Nevertheless, after data augmentation, the model showed exceptional accuracy in recognising these numbers, making it a valuable tool for Dioula speakers. Data augmentation also successfully mitigated the common problem of overfitting in models trained with limited data by introducing variability into the training data, which improved generalisation across speech patterns and variations. While the study shows significant progress in dioula number recognition, it also highlights the need for continued refinement and development, with a focus on continuous data collection and fine-tuning to maximise the accuracy and applicability of the model. A comparative analysis with previous research highlights the unique contribution of this study, which strategically uses data augmentation to compensate for data limitations, resulting in significant increases in accuracy. In summary, the main findings of the study highlight the crucial role of data augmentation in overcoming data scarcity in speech recognition for underserved languages such as Dioula.

These results show that speech recognition models, when equipped with effective data augmentation techniques, can significantly improve their accuracy, making the technology more accessible and useful to the target language community. Further refinement and data collection are essential to realise the full potential of the models and achieve higher levels of accuracy and precision.

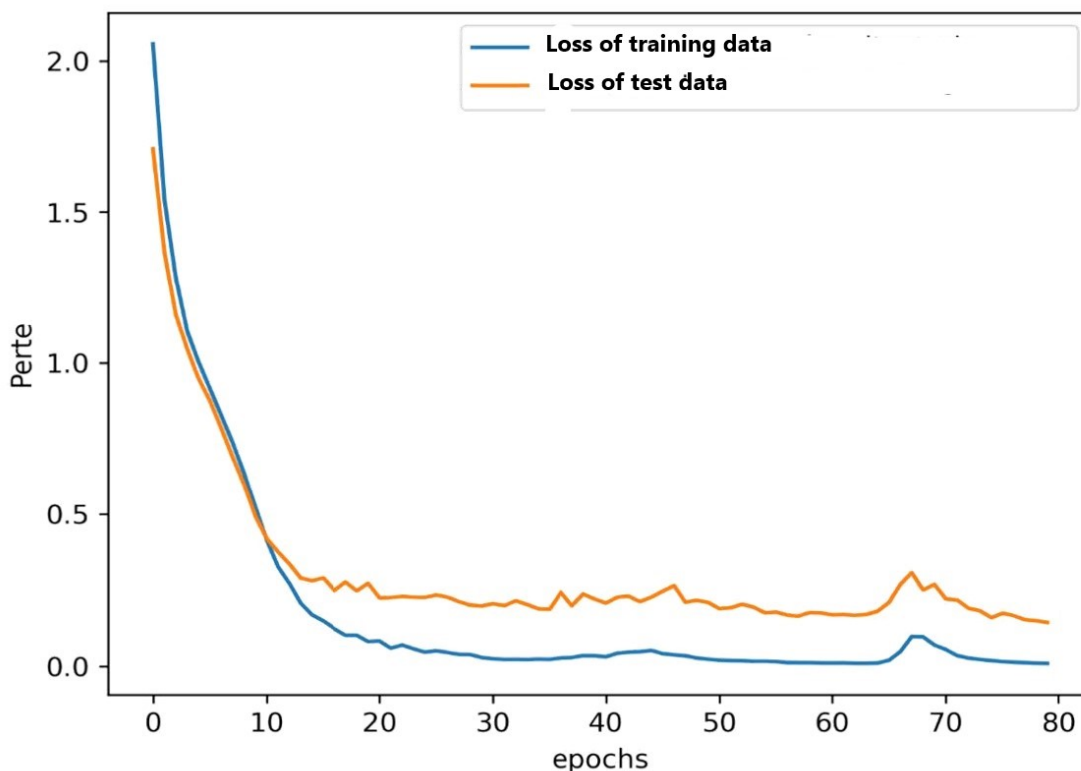


Figure 6.17 – Learning curve based on loss with augmented data

6.5 Limitations

The study encountered several limitations that should be taken into account in future developments of speech recognition for the Dioula language. One important limitation is the narrow scope of the dataset, which is mainly focussed on the recognition of numbers. This narrow focus restricts the applicability of the model to a limited linguistic domain and emphasises the need for more comprehensive datasets that include different linguistic elements and conversational contexts. To achieve this, future research should prioritise the collection of comprehensive datasets that reflect real language use and ensure the adaptability of the model in different linguistic scenarios.

Another important limitation concerns the size of the sample and the diversity of the participant group. While the study included participants from Dioulaphone, a larger and more diverse group of participants would allow for a more comprehensive understanding of the nuances and variations of the Dioula language. Including participants from different linguistic backgrounds within the Dioula-speaking community could lead to data that better represents the subtleties of the language. Collaboration with local language experts and community members is essential to expand data sets, improve modelling accuracy and ensure the relevance and effectiveness of the technology for the wider Dioula-speaking population.

7 Contribution to Mozilla Common voice speech dataset for "Dioula" Language

This research project focuses on the further development of language technology and the promotion of the linguistic integration of the Dioula-speaking community. At the centre of the initiative is the collaboration on the Mozilla Common Voice Initiative⁵, a collaborative platform for voice datasets. The main goal is to create a robust Dioula voice dataset within this platform to improve voice technology and facilitate the development of voice-enabled digital health solutions. The process involves translating the Common Voice interface into Dioula, collecting a diverse dataset of Dioula sentences, capturing data through Common Voice and validating the collected data. The outcomes of the project include the successful creation of a Dioula

5. <https://commonvoice.mozilla.org/dyu/speak>

language dataset, extensive voice recordings and a community engagement workshop. The results emphasise the transformative impact of data augmentation techniques, overcoming challenges and the importance of community engagement. The impact extends to the development of voice-activated digital health solutions tailored to low-literate people in Dioula communities, promoting inclusion and improving health literacy. Ultimately, the initiative will help create an accessible digital health ecosystem for the Dioula-speaking population.

7.1 Context

This dedicated contribution to the Mozilla Common Voice initiative is an important step in promoting linguistic inclusion and technological empowerment of the Dioula-speaking community. Launched by Mozilla, the Common Voice Initiative is a collaborative platform that brings together a variety of language datasets to drive advances in language technology across different linguistic landscapes.

By creating a robust Dioula interface within the Common Voice platform, this initiative seeks to bridge the digital language divide and ensure meaningful participation of the Dioula-speaking population in the digital sphere. Mobilising and engaging Dioula communities in this effort promises not only to enrich the Common Voice dataset, but also to foster a sense of ownership and active participation in technological advancements in their language.

The fundamental goal is to create a speech dataset tailored to the Dioula language, enabling the development of efficient voice-enabled digital health solutions. This approach is expected to revolutionise access to critical health information for people with limited literacy skills, improve their health literacy and empower them to make informed decisions about their wellbeing. As such, this initiative is a critical step towards using technology to overcome language barriers and promote a more inclusive society.

7.2 Methods

The creation of a Dioula speech corpus on the Mozilla Common Voice platform followed a series of steps as shown in Figure 6.18:

Step 1: Translation of the Common Voice interface. The journey began with the translation of the Common Voice interface into Dioula. This was a crucial step to ensure that Dioula speakers could seamlessly access and navigate the platform. Working closely with native Dioula speakers who had language skills, the interface elements, including menus, buttons and instructions, were carefully translated into Dioula. The goal was not only linguistic accuracy but also cultural context and usability to remove language barriers and make the platform welcoming to Dioula speakers. This step was fundamental in promoting inclusion and accessibility in the field of language technology.

Step 2: Collecting sentences. The second step was to compile a large and diverse dataset of 5,000 Dioula sentences. These sentences should authentically reflect the linguistic depth and everyday use of Dioula. Collaboration with native Dioula speakers, students and the wider Dioula-speaking community was crucial. Brainstorming sessions, exploration of existing resources and careful attention to content diversity were the driving forces. The resulting dataset included different contexts, topics and grammatical structures, including idiomatic expressions and proverbs, to ensure that it reflected authentic Dioula language use. This step laid the foundation for effective speech recognition and speech synthesis systems tailored to Dioula.

Step 3: Data acquisition through Common Voice. Adapting the Common Voice platform to Dioula was the third important step. Detailed instructions were created to guide participants in recording their speech with precision in terms of pronunciation, intonation and clarity. The platform's interfaces were designed to be user-friendly and complemented by awareness campaigns to encourage active participation by the Dioula-speaking community. Additional resources such as audio recording tips and pronunciation guides were provided to support participants in creating high-quality recordings. Participants' rights and data security were protected through a robust privacy and consent framework that enables ethical data collection.

Step 4: Validation of the data. Validation of the collected data was the final crucial step to ensure the quality and reliability of the corpus. Native Dioula speakers from different backgrounds were recruited as validators, covering different dialects, age groups and language levels. To maintain a standardised and objective validation process, comprehensive guidelines were established covering aspects such as pronunciation, fluency and adherence to Dioula language conventions. Validators were trained and followed a consensus-based assessment process to ensure consistency and minimise bias. Validation results were monitored and analysed on an ongoing basis to continuously refine the validation process.

In addition, a one-day workshop was organised in September 2023, attended by 17 native speakers from Bobo Dioulasso, including 6 men and 11 women. These participants actively contributed to both data collection and validation, further enriching the Dioula corpus and reinforcing the commitment to inclusion and community involvement in this project.

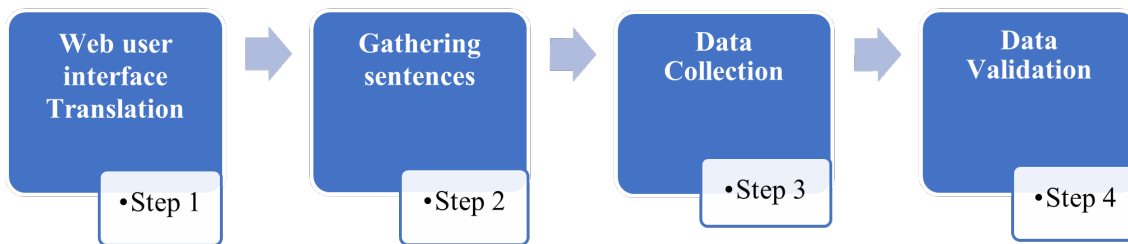


Figure 6.18 – Speech dataset creation process on Mozilla Common Voice platform

7.3 Results

First and foremost, the team successfully created a Dioula speech dataset. To do this, we translated the Common Voice interface in Dioula so that Dioula speakers could easily navigate the platform. We also created a diverse and representative dataset of Dioula sentences covering different linguistic contexts and everyday language use. This dataset contributed significantly to the richness and relevance of the Dioula speech corpus. In addition, the project collected a considerable number of voice recordings in the Dioula language through the Common Voice platform. These recordings were subjected to a rigorous data validation process to ensure the quality and reliability of the data collected. To facilitate the development of speech recognition models, the collected data was carefully divided into training, development and testing groups for the Dioula language.

In parallel, the research project also included a workshop on mobilisation and speech recording. This workshop played a crucial role in engaging the Dioula-speaking community and entailed the participation of at least 20 people. Participants were provided with the necessary instructions and recording equipment, resulting in an extensive corpus of at least 1 hour of validated Dioula speech samples. As shown in Figure 6.19 and 6.20, 29 Dioula speakers recorded and validated approximately 36.66 kB of speech data, which equates to around 1 hour of audio. This data is available for download. Progress is at 100%, and 5028 sentences have been uploaded, awaiting volunteers to contribute by recording their voices.

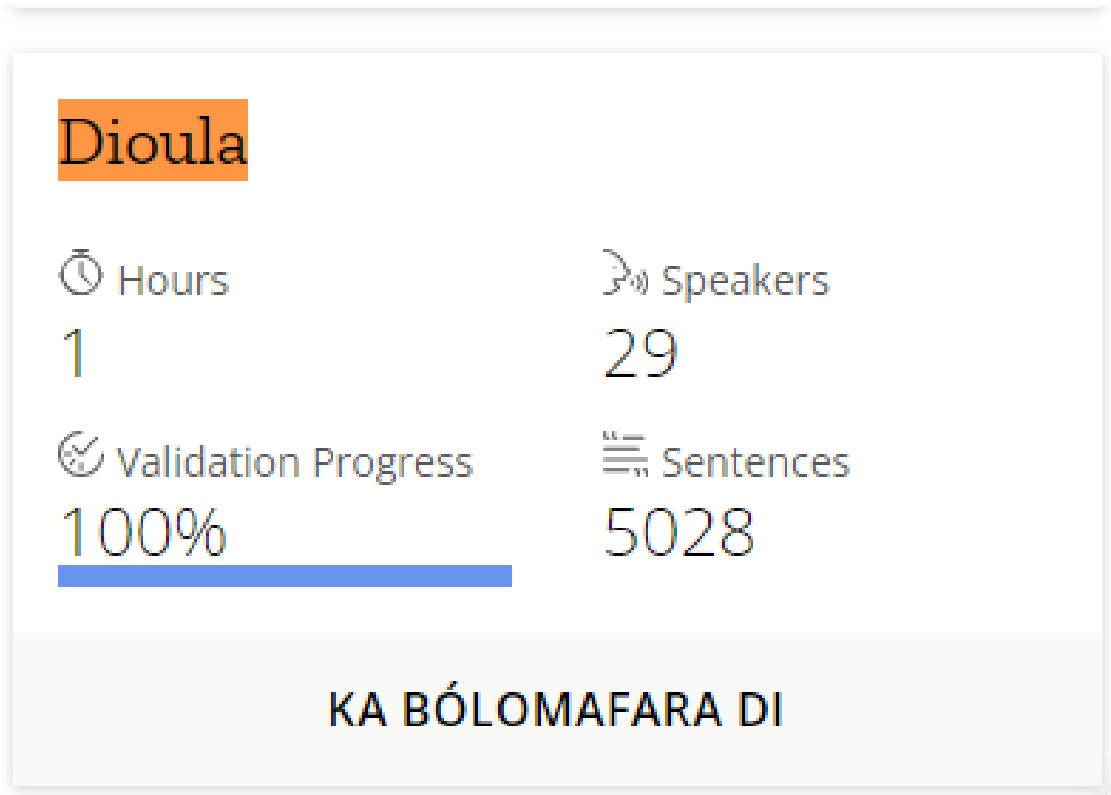


Figure 6.19 – Dioula language interface for voice collection

Download the Dataset

We've made some changes. Delta Segments just contain the most recent clips since the last release. [Read more about this work](#).

Select the desired language dataset and choose the version you wish to download.

Language
Dioula

Version	Date	Size	Recorded Hours	Validated Hours	License	Number of Voices	Audio Format
Common Voice Corpus 16.0	12/19/2023	8.08 MB	1	1	CC-0	20	MP3
Common Voice Delta Segment 16.0	12/19/2023	6.78 MB	1	1	CC-0	14	MP3
Common Voice Delta Segment 15.0	9/14/2023	1.27 MB	1	1	CC-0	5	MP3
Common Voice Corpus 15.0	9/14/2023	1.31 MB	1	1	CC-0	6	MP3
✓ Common Voice Corpus 14.0	6/28/2023	36.66 kB	1	1	CC-0	1	MP3
Common Voice Delta Segment 14.0	6/28/2023	157 byte	0	0	CC-0	0	MP3
Common Voice Corpus 13.0	3/15/2023	36.5 kB	1	1	CC-0	1	MP3

* Email

* You are prepared to initiate a download of **36.66 kB**

* You agree to not attempt to determine the identity of speakers in the Common Voice dataset

You want to join the Common Voice mailing list

Enter Email to Download

DONATE

Why an email? We may need to contact you in the future about changes to the dataset, an email provides us a point of contact.
sha256 checksum:
081c2561ec11582bfe5f0b2292d8f0c2b4625f91e7e66ede85c6e99deacc4

Mozilla Common Voice is the world's most diverse crowdsourced open speech dataset - and we're powered entirely by donations. It costs almost a million dollars a year to host the datasets and improve the platform for the 100+ language communities who rely on what we do. If you value open, inclusive data - donate today!

Figure 6.20 – Dioula language validated speech dataset available for download.

7.4 Findings

The impact and importance of the Dioula speech corpus cannot be overstated. It represents a critical milestone for the development of speech recognition technologies. By providing speech-enabled applications and services in the Dioula language, this corpus can improve digital accessibility for Dioula speakers. It can also contribute to promoting linguistic diversity and inclusivity in the field of speech technologies. The availability of a robust Dioula language corpus enables the development of more accurate and effective speech recognition models specific to the Dioula language.

The mobilisation and speech recording workshops provided important insights. These events successfully engaged the Dioula-speaking community and fostered a sense of ownership and enthusiasm among participants. In addition, the workshops served as platforms for collaboration and knowledge sharing and created awareness of the importance of speech corpora and recording techniques. They also provided valuable insights into the preferences and needs of the Dioula-speaking community in relation to language-based technologies.

However, the research project was not without challenges. It encountered limited resources and technical constraints. Nevertheless, these challenges were effectively overcome through collaborative efforts, optimisation of resources and the use of existing platforms. The project has shown the importance of community engagement and continuous support, which have been instrumental in its success. The lessons learned in overcoming these challenges offer valuable lessons for future initiatives aimed at creating language corpora for underrepresented languages and promoting inclusivity in language-based technologies.

At least 20 people from the Dioula-speaking community participated in the workshop. Participants were provided with the necessary instructions and recording equipment to record their voices. The results of the workshop led to the creation of an extensive corpus with at least 1 hour of validated Dioula voice samples. This corpus serves as a valuable resource for further research and development of voice translation technology for the Dioula language.

In summary, this project is a critical step towards the development of speech-enabled digital solutions, particularly in the area of access to digital health resources tailored to the specific needs of Dioula-speaking communities, especially those with limited literacy.

7.5 Implications

The preliminary results of these studies contribute to the early development of voice-activated digital health solutions tailored to low-literacy populations in Dioula communities. The research highlights the potential benefits of data augmentation

techniques in addressing data scarcity and improving the accuracy of speech recognition models, which could facilitate technology access for the Dioula-speaking community and promote inclusion in digital health.

By utilising an enriched Dioula language corpus and engaging the community, the project will begin to develop customised speech-enabled digital health solutions. These solutions aim to bridge communication gaps and enable people with low literacy skills to seamlessly access health information and services. The initial implementation of data augmentation techniques in creating more accurate speech recognition models holds promise for developing user-friendly, efficient tools tailored to the needs of Dioula-speaking communities. By integrating speech technology, the project aims to improve the health literacy and outcomes of low-literate people in Dioula communities. By engaging the community and understanding the nuances of the Dioula language, the goal is to create culturally sensitive, linguistically relevant digital health solutions that can increase their effectiveness and impact.

Overall, this early initiative modestly aims to promote access to digital health resources for people with low literacy skills in Dioula communities. Through the use of voice-driven technology, it aims to promote an inclusive digital health ecosystem that will potentially help improve the health literacy and well-being of the Dioula-speaking population.

8 Challenges and Limitations in Building the Dataset

The project aimed to support Mozilla's Common Voice initiative for the Dioula language, encountering limitations primarily due to resource constraints and technical complexities. These challenges affected the project's efficiency and the thoroughness of data collection and validation. They also raised concerns about the accuracy and quality of the Dioula dataset, highlighting the need for more tailored technologies for underrepresented languages.

Despite these challenges, 17 participants were engaged in data collection and validation, underscoring the value of community involvement. However, the project's reliance on a small number of participants suggests potential for broader community engagement.

These constraints underscore the ongoing need for research and development to address obstacles in developing language datasets for languages lacking resources and technological support. This focus is crucial for advancing language technologies and fostering inclusivity in digital language initiatives.

9 Conclusion

This chapter addresses key challenges in speech technology and speech recognition, representing significant progress for the Dioula language. The successful development of a robust database and speech recognition model tailored to recognize wake words 1, 2, 3, and 4 marks a critical advance in improving speech recognition capabilities specific to the Dioula language. This development underscores the potential to enable access to speech-enabled digital health resources in the Dioula language, particularly for low-literate communities. As part of enhancing our IVR system, integrating this trained model for recognizing numbers 1, 2, 3, and 4 into our interactive speech server seems promising. This integration will streamline navigation through language-based menus in the local Dioula language for users with limited language proficiency, allowing access to important health information without the need for advanced numeracy skills. Moreover, the contribution to the Mozilla Common Voice Speech Dataset for the Dioula language signifies an important milestone in promoting linguistic diversity and inclusion in the field of speech technologies. Emphasizing the development of language resources and fostering active engagement with the Dioula-speaking community, this initiative empowers Dioula speakers and facilitates their access to critical services, education, and economic opportunities. These results extend beyond the local context, catalyzing similar efforts dedicated to supporting underrepresented languages, particularly those prevalent in Africa. By promoting the exchange of experiences and knowledge, the aim is to galvanize collective efforts in the field of language technology and promote the integration of diverse language communities.

Overall, these initiatives underscore the transformative potential of technology in fostering inclusion and equitable access to digital resources, contributing to a more diverse and accessible digital landscape. Notably, the focus on enhancing health literacy in Dioula-speaking communities showcases the profound impact of technology in promoting community well-being and facilitating access to crucial health information.

Chapter 7

Discussions and Recommendations

1 Discussions

Effective healthcare for low-literacy populations requires careful consideration of the essential functions of mobile healthcare solutions. Our study looks at the acceptance factors of the 3-2-1 IVR service and highlights the critical elements that influence the acceptance of the service by low-literacy populations. The central role of perceived ease of use, compatibility, privacy and usability is of paramount importance. Building on previous research, we emphasise the importance of user-friendly interfaces that are tailored to users' existing technical knowledge. In addition, we addressed the specific technological needs of low-educated communities, emphasising a preference for local languages and advocating for user-centred design.

These findings contribute to ongoing efforts to develop culturally appropriate mobile health solutions that bridge health literacy gaps and promote healthier practices in marginalised populations. The study advocates for optimised user interfaces, voice-driven interactions and offline functionality to ensure ease of design and accessibility in areas with limited connectivity.

1.1 Essential functionalities for low literates

Acceptance of the 3-2-1 IVR service: Our study highlights the importance of several key factors influencing the acceptance of 3-2-1 service in low-literacy populations. The results are consistent with previous research findings and highlight that perceived ease of use and compatibility play a crucial role in users' intention to use the 3-2-1 service. This highlights the importance of user-friendly interfaces and their adaptation to users' existing technical knowledge [Campbell, 2017; Klingberg, 2020]. In addition, addressing privacy concerns and fostering trust and enjoyment are critical to the acceptance and use of the 3-2-1 service. This highlights the importance of ensuring data security and creating engaging user experiences to drive adoption [Chang, 2013; Dhagarra, 2020; Ebnehoseini, 2020].

Users technological needs: Our research highlights the importance of tailoring mobile health services to the specific needs of low-education communities. In particular, the preference for local languages, especially Moré, highlights the accessibility and comprehension benefits associated with the mother tongue and is consistent with previous studies that emphasise the value of language familiarity [EDIM, 2013]. Furthermore, the preference for a language interface and the diverse feedback on serious games confirm the effectiveness of user-centred design approaches, which emphasise the need for intuitive interfaces and the potential benefits of including engaging elements to enhance the user experience [Browne, 2014; Mueller, 2020].

These findings from our study contribute to ongoing efforts to develop culturally appropriate and accessible mobile health solutions. The emphasis on language appropriateness and user-centred design serves as a guiding principle for creating interventions that are responsive to the cultural and linguistic diversity of underserved communities [Luquis, 2021]. By integrating local languages and prioritising usability, these guidelines aim to close gaps in health literacy and promote healthier practices among marginalised populations.

In addition, our study highlights the essential functionalities needed to develop effective mobile health solutions tailored to the challenges of communities with limited resources and education. The focus on streamlined user interfaces, voice-driven interactions and offline functionality addresses the specific needs of users with low literacy skills and ensures simple design and accessibility in areas with limited connectivity [Rogers, 1999; Tomlinson, 2013]. With a holistic approach that focuses on the differentiated experiences of underserved populations, our research advocates for the integration of user-centredness and a comprehensive understanding of the multi-faceted challenges of these populations.

1.2 Evidence of the impact of voice and local language enabled technology

The study conducted in Pazani camp in Burkina Faso offers valuable insights into the transformative impact of local languages and language-guided interfaces in improving health literacy among underprivileged populations, with a focus on IDPs and their malaria health literacy. Previous research has consistently highlighted the multiple challenges faced by IDP in accessing timely medical assistance and the critical role of tailored health education strategies that take into account linguistic and cultural aspects [Polonsky, 2013]. The initial observations of the study underline the low level of health literacy among participants, highlighting the urgent need for targeted health education interventions [A Moran, 2013]. Through the introduction of a multilingual IVR service, the study indeed demonstrated a significant improvement in participants' health literacy and showed remarkable improvements in knowledge, attitude and practice in the intervention group. These findings highlight the central role of local languages in addressing prevalent misconceptions about malaria and promoting evidence-based health practices such as mosquito control and the use of mosquito nets [Ghahremani, 2014].

Furthermore, the comparison between the local language version of the IVR service and the French version illustrates the profound impact of integrating language-driven interfaces into local languages. This comparison highlights the transformative potential of voice-controlled technology in facilitating effective health communication and education in underserved populations. The 3-2-1 service's voice-controlled interface not only addresses the language needs of the community but also improves accessibility by enabling users to receive important health information through intuitive voice commands.

The research undertaken in this study offers compelling empirical evidence that highlights the positive impact of voice-activated mobile health technologies, particularly when deployed in local languages. By showcasing the efficacy of voice-activated technologies in surmounting barriers posed by limited literacy, the study accentuates their potential to significantly enhance health outcomes within underserved communities. This corroborates previous research emphasizing the instrumental role of voice-activated technologies in augmenting accessibility and user engagement in healthcare interventions, thereby reinforcing the relevance and significance of the current study's findings [López, 2011; Wang, 2018]. Voice-activated technology within mobile health solutions serves as a potent instrument for enhancing user accessibility and engagement, particularly in communities where literacy levels are constrained. By providing an alternative mode of communication that transcends traditional text-based interfaces, voice-controlled technology fosters a more inclusive approach to disseminating health information and delivering health services. This inclusive approach facilitates increased participation and comprehension among diverse populations, ultimately contributing to improved health literacy and better health outcomes. The empirical evidence articulated in this study underscores the pivotal role of voice technology as a transformative tool in healthcare and underscores its potential to bridge communication gaps and promote health equity in underserved communities. By harnessing the capabilities of voice-enabled technology, mobile health solutions can effectively cater to the diverse linguistic and literacy requirements of communities, thereby facilitating access to vital health information and services. The study's findings illuminate the promise of voice technology in fostering positive health outcomes and advancing greater inclusivity in healthcare delivery

Overall, the study's findings highlight the critical role of local languages and voice-activated interfaces in promoting health literacy in Burkina Faso's communities, particularly among the IDP population. By integrating these components, the study contributes to the ongoing discourse on effective health literacy interventions and highlights the importance of tailored approaches that take into account linguistic and cultural nuances to ensure equitable access to key health information [Jacobs, 2016].

1.3 Development of an AI-driven prototype for Health Information delivery

The study presents a novel IVR service tailored to improve the health literacy of people with low levels of education about COVID-19. Most notably, participants found the service easy to navigate without assistance and 72.22% expressed a desire to use it frequently. In addition, the system's ability to integrate and accessibility were highly praised, especially due to its ability to be used in the local language. Impressively, the IVR service achieved an excellent numerical usability score of 78.75, which is in line with the positive results of a study conducted by N. Wolfe and colleagues in Guinea [Wolfe, 2015]. However, the lack of speech recognition for African languages highlights the need for further research, particularly concerning the integration of voice-driven interactions, which could be of great benefit to people with limited numeracy skills. Initiatives such as Mozilla's Common Voice Project ¹, which focuses on building an inclusive speech database, are an important step towards democratising speech technology for all.

The development of an AI-driven prototype for health information dissemination is a significant step in health technology. This prototype is a concrete demonstration of the transformative potential of AI in delivering vital health information, especially in local languages such as Dioula. This integration of AI into healthcare solutions aligns with previous research that recognises its ability to improve access to information and streamline the delivery of critical health services [Sharma, 2021]. Through the use of AI-driven platforms, this prototype effectively bridges the gap between complex health information and people with limited literacy skills, promoting health literacy and empowerment in underserved communities.

1. <https://commonvoice.mozilla.org/fr>

Furthermore, the use of the AI-driven prototype highlights the role of technological innovation in promoting personalised and interactive health experiences. The use of AI-driven IVR systems enables tailored delivery of health information, promoting engagement and active participation in health management. Previous research has highlighted the potential of AI-driven health solutions to increase patient engagement and self-management, leading to better health outcomes and quality of life [Topol, 2019; Choukou, 2021].

The prototype's ability to provide health information in local languages, including Dioula, not only promotes linguistic inclusion but also deepens cultural relevance within target communities. By adapting the provision of health information to local languages and cultural contexts, the prototype improves the accessibility and comprehensibility of key health resources, contributing to informed decision-making and empowerment in diverse language communities. This patient-centred and culturally sensitive approach is a significant step towards equitable healthcare and highlights the transformative impact of AI technology in advancing health literacy and community well-being.

1.4 Creation of a Dioula language dataset

Our comprehensive evaluation of the Dioula speech recognition model has provided valuable insights into its performance, strengths and limitations. Most importantly, our implementation of data augmentation has proven to be a critical factor in improving the overall efficiency of the model. By systematically expanding our training dataset, data augmentation has effectively improved the accuracy of the model while mitigating losses. This technique introduced significant variability into the training data that allowed the model to generalise across different language patterns and variations, solving the initial problem of overfitting due to limited data availability. However, it is important to recognise that further improvements are needed to fully optimise the accuracy of the model. While the model has proven that it can detect Dioula numbers, further refinements and data collection offer the potential for even greater precision and broader applicability. Drawing on insights from previous research provides an important context for our findings. Febe de Wete et al [De Wet, 2017], Ewald van der Westhuizen et al [Westhuizen, 2021] and Moussa Doumbouya et al [Doumbouya, 2021] pursued different foci, employed different methods, used different datasets and implemented different techniques. The study by Febe de Wete et al.[De Wet, 2017] on data sharing in HMM-based ASR systems for underserved languages underlined the importance of sharing data between languages but showed that there is limited improvement in phonetic recognition performance by merging data from different sources. The work of Ewald van der Westhuizen et al. on developing speech recognition systems for underserved languages such as Bambara and Maasina Fulfulde showed improved speech recognition accuracy by strategically including certain additional languages [Westhuizen, 2021]. Moussa Doumbouya et al. contributed to the development of speech recognition models for Maninka, Pular and Susu languages and demonstrated the effectiveness of WAwav2vec features compared to Mel spectrograms [Doumbouya, 2021].

In contrast, our study addressed the fundamental challenge of limited initial training data for Dioula language recognition by strategically using data augmentation to combat data scarcity. This approach resulted in a significant increase in accuracy from 51% to 96% and highlights the potential of data augmentation as a critical strategy for improving speech recognition performance in the presence of limited data. Furthermore, the creation of a comprehensive and reliable data set for the Dioula language represents a significant breakthrough in the field of speech-based AI solutions, particularly in the context of promoting health literacy and accessibility in underserved communities. By addressing the long-standing lack of language-specific resources, this research project not only lays the foundation for the development of effective and culturally sensitive AI-powered language technology but also advocates for a more inclusive and equitable approach to the dissemination of and access to health information.

This comprehensive Dioula language dataset serves as a foundational resource for further advances in AI-powered health solutions tailored to the linguistic and cultural nuances of the Dioula-speaking population. Its integration with AI-driven language technologies facilitates the development of more sophisticated and context-aware NLP models that enable better communication and interaction between AI systems and Dioula-speaking users. In addition, this dataset plays a central role in promoting the preservation and revitalisation of local languages and cultural heritage, highlighting the importance of linguistic diversity and inclusion in the broader framework of health information dissemination and community engagement.

Overall, the development of this dataset represents a critical step in the use of AI and linguistic resources to bridge communication gaps, reduce inequities, and ultimately promote more effective and accessible health services for marginalised and underserved populations. Its creation highlights the transformative potential of language-based AI solutions to promote health equity and empower communities with limited access to health resources and information.

2 Implications and Recommendations

The implications arising from the multi-faceted exploration of essential functions, the impact of voice and context-based technology and the development of an AI-driven prototype emphasise critical considerations for the design of effective health interventions. Understanding these implications is critical to developing recommendations that prioritise accessibility, cultural relevance and inclusivity. The following sections address the nuanced findings that emerge from each aspect of the study and provide recommendations that reflect the transformative potential of technology in improving community health literacy and well-being, particularly among marginalised populations with limited access to traditional health resources.

2.1 Implications of essential functionalities for low literates

The essential requirements needed to develop a Mobile Health Information Service (MHIS) designed for underserved, low-literate populations, gathered from case studies and summarized in Section 3 of Chapter 5, are presented in the table 7.1. The study underscores the significance of voice and local language integration in mobile health solutions for low-literacy communities. The findings emphasize the critical role of user-friendly interfaces, trust-building measures, and intuitive designs in encouraging the adoption and sustained usage of health services. Additionally, the study highlights the importance of language familiarity and engaging elements, advocating for tailored interventions responsive to the diverse linguistic and cultural backgrounds of underserved communities. These implications call for the development of mobile health solutions that prioritize simplicity, inclusivity, and cultural relevance, promoting equitable health literacy and practices among marginalized populations.

Recommendation:

Functional Requirements

- Content in the local language: Prioritize local language integration to enhance accessibility and comprehension, fostering a deeper connection with users and promoting inclusive health education.
- Voice User Interface: Include interfaces for audio and voice tools for information sharing.
- Incorporate serious games: Integrate the option for serious games for young end users.
- Energy consumption and electricity: Ensure low power consumption by minimizing animation and graphics and reducing background activity.
- Internet connectivity: Operate with minimal internet dependency or offline with minimal bandwidth usage.

Non-Functional Requirements

- Security and privacy: Protect users' data with appropriate security measures based on data sensitivity.
- Reliability: Provide accurate and trustworthy information.
- Usability (Ease of Use): Design for user-friendly, effective, and efficient interactions.
- Enjoyability: Create a culturally appealing system for the target population. Compatibility: Ensure compatibility with the needs and skills of low-literate users.

Table 7.1 – Requirements for designing a Mobile Health Information Service for underserved low literate communities

Functional requirements	Description
Content in the local language	The system must incorporate national languages of the local population
Voice User Interface	The system must include interfaces that allow the use of audio and voice tools for information sharing
Incorporate serious games	The system must include the possibility of serious games.
Energy consumption and electricity	The system must have low power consumption by using minimal animation and graphics and less background activity
Internet connectivity	The system must have minimal internet dependency or operate offline or with minimal bandwidth usage.
Non-Functional requirements	Description
Security and privacy	The system shall ensure that users' data are protected by security measures appropriate to the sensitivity level of the data.
Reliability	The system shall ensure that the information provided is accurate and trustworthy.
Usability (Ease of Use)	The system shall be designed to be easy to use, effective, and efficient while satisfying users.
Enjoyability	The system must be designed based on the culture and demographic profile of the target population to ensure that it will appeal to users.
Compatibility	The system must be compatible with low-literate needs and skills.

2.2 Implications of the impact of voice and local language-enabled technology

The study's findings underscore the transformative potential of voice-activated technology and local language integration in enhancing health literacy and accessibility within underserved communities. The research highlights the positive impact of

voice-controlled interfaces in fostering inclusive health communication and user engagement, particularly among populations with limited literacy. Furthermore, the study emphasizes the pivotal role of local languages in dispelling misconceptions and promoting evidence-based health practices, emphasizing the need for tailored health education interventions considering linguistic and cultural nuances. These implications emphasize the significance of voice technology in bridging communication gaps and promoting health equity, advocating for the widespread adoption of inclusive language-driven health interventions.

Recommendation

- Voice-Enabled Technology: Foster the integration of voice-activated interfaces in health technologies, enabling inclusive and engaging health communication among diverse populations.
- Culturally Relevant Education: Develop tailored health education interventions that consider linguistic and cultural nuances, promoting evidence-based health practices and addressing prevalent misconceptions within underserved communities.

2.3 Implications of the development of an AI-Driven prototype for Health Information delivery

The study's exploration of an AI-driven prototype highlights the transformative impact of AI technology in promoting health literacy and community well-being, particularly among populations with limited education. The research underscores the significance of personalized and culturally sensitive health information delivery, emphasizing the role of AI-driven platforms in bridging the gap between complex health information and individuals with limited literacy skills.

Additionally, the study emphasizes the need for further research in integrating voice-driven interactions for improved accessibility and engagement, advocating for initiatives that democratize speech technology and promote linguistic inclusivity. These implications emphasize the transformative potential of AI in health information dissemination, fostering informed decision-making and empowered health management among underserved communities.

Recommendation

- Enhanced AI Integration: Further integrate AI technologies to deliver personalized health information, fostering inclusive and empowered health management among underserved populations.
- Voice Recognition Advancements: Invest in research and development initiatives to enhance voice recognition technologies, promoting linguistic inclusivity and democratizing speech technology for all.

2.4 Implications of the creation of a Dioula language dataset

The study's creation of a comprehensive Dioula language dataset represents a significant breakthrough in promoting health literacy and accessibility in underserved communities. The research highlights the transformative potential of linguistic resources in bridging communication gaps and promoting inclusive health services, emphasizing the pivotal role of data augmentation in enhancing speech recognition performance and mitigating data limitations. Additionally, the study advocates for the preservation and revitalization of local languages, promoting linguistic diversity and inclusion in the dissemination of health information. These implications underscore the critical role of language-based AI solutions in promoting health equity and empowerment among communities with limited access to health resources, emphasizing the need for further research to optimize speech recognition capabilities and promote linguistic inclusivity.

Recommendation

- Data Augmentation Strategies: Invest in data augmentation techniques to enhance speech recognition performance, mitigating data limitations and improving accuracy in underserved language contexts.
- Linguistic Preservation: Promote the preservation and revitalization of local languages, fostering linguistic diversity and inclusivity in health information dissemination and community engagement.

3 Contributions

The thesis contributes to advancing health literacy through mobile technology adoption among underserved communities. Focused case studies delve into the implementation of an AI-driven Interactive Voice Response (IVR) prototype crafted for distributing health information in Dioula language. This research significantly enhances health literacy and the utilization of mobile technology in communities lacking resources. Its contributions encompass evaluating the impact of local language-based mobile technologies and gauging the effectiveness of voice-enabled devices in marginalized settings. These substantial

contributions, supported by case studies and empirical evidence, emphasize the vital significance of inclusive mobile health design, the integration of AI-driven prototypes, and the creation of speech datasets for languages facing disadvantages.

3.1 Evidence on the effectiveness of voice-enabled mobile health devices

The thesis contributed significantly by examining the impact of local language-based mobile technologies on enhancing health literacy among marginalized, low-literate communities. Case Study 3, conducted in the Pazani camp in Burkina Faso, focused on internally displaced individuals, revealing essential insights. The malaria literacy assessment initially displayed moderate baseline scores for knowledge (52.6% intervention, 51.84% control) and attitudes (70.74% intervention, 74.3% control). Despite this, misconceptions about malaria causes persisted in both groups. Following the introduction of the 3-2-1 service via IVR to improve health literacy, both groups exhibited improvements. However, the intervention group, especially those using the local Moré language, demonstrated substantial knowledge (30.33%), attitude (21.77%), and practice (35.38%) gains compared to the French-speaking control group (15.98%, 14.58%, and 14.5%, respectively). These significant outcomes underscore the immediate need for targeted health education initiatives prioritizing evidence-based malaria prevention strategies. The study showcases the immense potential of IVR services in local languages to significantly enhance health literacy, combat misinformation, and augment knowledge about malaria, particularly among vulnerable populations in SSA, such as Burkina Faso.

3.2 Contribution to the identification of guidelines for designing inclusive mobile health for low literate

Our research contributions emerged from the scrutiny of mobile technology features, primarily showcased in Studies 1 and 2, revealing substantial limitations within existing mobile solutions regarding inclusivity for low-literacy populations. Only 16% of these solutions considered incorporating local languages. Moreover, Case Study 4 specifically delved into designing mobile health information services tailored for low literacy, outlining crucial factors that influenced the adoption of the 3-2-1 mobile IVR Service. The study underscored the critical roles of usability, security, trust, and compatibility, with Perceived Ease of Use accounting for 20.3% and Perceived Compatibility for 15.7%, among other significant factors. Additionally, Case Study 5 illuminated preferences in mobile health services, indicating a pronounced preference for the local Moré language, particularly among distinct demographic groups. These case studies make an important contribution by providing practical and culturally relevant guidelines for the development of mobile health solutions. These guidelines focus on two crucial aspects: technical functional requirements and non-functional requirements.

Technical functional requirements: The work highlights the importance of integrating local languages into mobile health solutions. By incorporating native languages, these solutions can effectively break down language barriers and ensure that health information is accessible to a variety of communities. It also highlights the integration of a language interface that provides users, especially those with limited literacy skills, with a more intuitive and user-friendly way to interact. This approach not only promotes inclusion but also creates a natural and engaging user experience.

Non-functional requirements: Usability remains one of the most important non-functional requirements addressed in this thesis. Simplifying user interfaces and navigation paths is important to ensure that people with different technical skills can easily access and benefit from mobile health services. In addition, improving compatibility with existing technologies is emphasised. This compatibility enables seamless integration of the solutions into the daily lives of the users and thus promotes lasting involvement and acceptance in the target groups. In summary, the contribution of this work is to offer comprehensive guidelines that take into account the technical and non-functional aspects of developing mobile health solutions and ensure that these solutions are not only linguistically appropriate but also highly effective in communicating important health information in local languages. Underlying this approach is a deep understanding of the important role that local languages play in promoting health literacy within communities, ultimately leading to better health outcomes and equity.

3.3 Creation of an AI-Assisted interactive voice service prototype

A key milestone in this research is the practical implementation of an AI-powered IVR proof of concept specifically tailored to disseminate health information in the Dioula language. Developing a context-aware AI prototype for COVID-19 literacy in Dioula (Case Study 7) demonstrated promising usability outcomes, with agreement of all the 18 participants on user-friendliness and SUS score of 78.75. This tangible demonstration highlights the effective use of AI technology to make important health information accessible to people with limited literacy skills. The prototype serves as a robust example of the immense potential that AI-powered mobile health solutions hold to significantly improve health literacy levels.

3.4 Development of speech dataset for underserved language

The thesis contributed to enhancing speech recognition accuracy for low-resourced languages like Dioula (Case Study 8). Through data augmentation, the model's accuracy soared from 51% to an 96%. These initial findings provide valuable insights into potential interventions for health literacy, technological limitations, and approaches to address language barriers. The development of a Dioula interface in Mozilla Common Voice marks a step forward in expanding the speech dataset, which is valuable for the creation of AI-powered mobile solutions aimed at addressing health literacy challenges among low-literate individuals.

4 Challenges and limitations of the work

The research endeavours encountered many obstacles due to the limited recruitment of participants for the various study cases. For example, there were 92 participants in study case 6, 97 participants in study case 3, and only 17 people participated in the Mozilla Common Voice project. This low number of participants posed a major challenge in collecting adequate data and thus prevented comprehensive findings from being obtained. In our studies, validated health literacy and eHealth literacy tools were not initially available in local languages such as Dioula, Moré, and Fula. Therefore, we commenced by using validated French versions of these tools and subsequently undertook the process of translation into the aforementioned local languages. In addition, mobilising resources for data collection was complicated and demanding and required careful attention to administrative protocols in the local environment. Administrative procedures included obtaining key authorisations, complying with local regulations and managing bureaucratic complexity, which significantly limited time and operational efficiency in data collection. These challenges highlighted the importance of innovative approaches to improve participant recruitment strategies and streamline administrative processes to ensure more effective and efficient data collection within the study.

General conclusion and perspectives

1 General conclusion

This thesis centers on addressing the challenges linked to health literacy in underserved communities, particularly those marked by low literacy rates. It aims to enhance health literacy within these communities by leveraging local languages and AI-driven voice systems while employing a user-centred design approach. Accessing and utilizing health information in *SSA* poses significant obstacles, compounded by the prevalence of foreign language content in digital health solutions and occasional design limitations that hinder meeting the needs of the local population.

The scope of this work encompasses field studies aimed at assessing the effectiveness of local languages and voice-based mobile health solutions. It also involves investigating the requirements for designing inclusive mobile health literacy interventions, proposing and evaluating a prototype of an AI-enabled mobile solution, and contributing to the development of speech datasets tailored for low-resourced languages like Dioula. These studies are aligned with our research questions as follows:

The first research question aimed to assess the impact of local language-based mobile technologies on improving the health literacy of marginalised, low-literate communities. Study case 3 conducted in the Pazani camp in Burkina Faso, which focussed on internally displaced people, provided crucial insights. The malaria literacy assessment initially showed moderate baseline scores for knowledge (52.6% intervention, 51.84% control) and attitudes (70.74% intervention, 74.3% control). However, misconceptions about the causes of malaria, such as diet, sun exposure, supernatural causes, and labour fatigue, persisted in both the intervention and control groups. After introducing the 3-2-1 service via IVR to improve health literacy, improvements were observed in both groups. However, the intervention group, particularly those who used the local Moré language, showed significant gains in knowledge (30.33%), attitude (21.77%) and practice (35.38%) compared to the control group who spoke French (15.98%, 14.58% and 14.5%, respectively). These significant results emphasise the immediate need for targeted health education initiatives prioritising evidence-based malaria prevention strategies. The study highlights the remarkable potential of IVR services in local languages. It shows that they can significantly improve health literacy, counteract misinformation, and significantly improve knowledge about malaria, especially among vulnerable populations in *SSA*, such as Burkina Faso.

Shifting the focus to the second research question, investigating key features and traits of mobile technologies used in health literacy interventions, laid the foundation for this inquiry. This exploration into mobile technologies within health literacy initiatives in *SSA*, encompassing study cases 1 and 2, revealed significant limitations in inclusivity for low-literacy populations. Among the varied initiatives scrutinized, only 16% of the identified solutions fully integrated local languages and voice services, while the reliance on the English language and internet-connected systems in mobile serious games posed notable hurdles for low-literacy communities. The necessity for internet access emerged as a significant challenge, impeding resource accessibility for individuals with limited literacy skills. Furthermore, study case 4 focused on designing mobile health information services tailored for low literacy and delineated crucial factors influencing the adoption of the 3-2-1 mobile IVR Service. The findings emphasized the pivotal roles of usability, security, trust, and compatibility, where Perceived Ease of Use accounted for 20.3%, and Perceived Compatibility for 15.7%, among other significant factors. Additionally, study case 5 highlighted preferences in mobile health services, indicating a strong inclination toward the local Moré language, particularly among specific demographic groups. Although 60.76% favored mobile health services with games overall, distinct age groups exhibited varying inclinations toward Serious Games, indicating diverse user preferences. Lastly, study 6, assessing health literacy among diabetic inpatients, identified essential gaps despite widespread smartphone access. The similarities in demographics and considerable health literacy disparities underscored the critical necessity for targeted interventions and educational programs, especially considering the prevalent limited formal education. In conclusion, these collective research findings underscore the pressing need to design more inclusive mobile health solutions by integrating local languages, prioritizing ease of use, and considering diverse user preferences. Addressing these aspects holds a significant potential to significantly enhance health literacy interventions and enhance accessibility for underserved communities, particularly those with limited literacy skills.

The third research question aimed to develop a context-aware, mobile-based AI prototype tailored for COVID-19 literacy in the Dioula language in Burkina Faso. The subsequent usability evaluation in study case 7, involving 18 participants aged 12-20 (66.7% female, 33.3% male), demonstrated positive outcomes. Results showed unanimous agreement (100%) on the service's user-friendliness, with 77.77% expressing confidence in its use and 72.22% desiring frequent usage. The System Usability Scale (SUS) scored an impressive 78.75 out of 100, highlighting excellent usability. This underscores the service's potential in enhancing health literacy, particularly among low-literacy individuals. While emphasizing the need for further speech recognition refinement for low-literacy populations due to data availability issues.

In pursuit of the fourth research question to bolster speech datasets for low-resourced languages like Dioula, we aimed to serve as an AI training resource for voice-enabled systems in low-literate communities. Study 8 specifically sought to contribute to speech datasets catering to such communities by collecting 1,700 audio samples (296.3MB, approximately 1.4 hours) concerning numbers 1, 2, 3, and 4. These datasets underwent AI model training using recognition techniques. To address the lower accuracy of the dataset, data augmentation expanded the data to 8,925 audios. Remarkably, this technique escalated the model's accuracy from 51% to an impressive 96%, highlighting the critical role of data augmentation in improving Dioula number recognition and speech models for such languages. The study underscores the pivotal role of data augmentation in bolstering speech recognition accuracy, specifically benefiting the Dioula-speaking community. However, continued refinement and data collection is crucial to fully harness the models' potential for heightened accuracy and precision. This dataset was detailed in case study 8, which propels AI solutions, particularly in numerical recognition. Our contribution through Mozilla Common Voice aids in crafting a speech dataset interface, promising to tackle health literacy gaps through tailored design and language integration. These contributions in speech datasets signify fundamental progress in developing speech-enabled digital solutions, especially in providing tailored digital health resources for Dioula-speaking communities with limited literacy. By integrating cutting-edge speech recognition technology, this project lays the groundwork for seamless access to crucial health information through voice-enabled platforms. Ultimately, this initiative bridges health literacy gaps and fosters equitable healthcare access in Dioula-speaking regions.

Overall, this thesis presents a significant paradigm shift in health literacy interventions, emphasizing the integration of AI-driven, language-specific, and voice-enabled technologies to empower low-literate communities. The assessment of local language-based mobile technologies revealed their potential to bolster health literacy, addressing prevailing limitations hindering inclusivity. Furthermore, the development and evaluation of AI-driven prototypes tailored for malaria and COVID-19 literacy showcased the transformative impact of technology on targeted health education. Notably, the endeavour to enhance speech datasets for languages like Dioula through data augmentation signifies an advancement, amplifying recognition accuracy. These collective efforts underscore the need for inclusive, AI-driven, and local language-based health solutions, promising improved health literacy and equitable healthcare access for low-literate communities.

2 Perspectives

The perspectives of this work can be described in the short, medium and long term to ensure the effective development of voice-controlled digital tools tailored to people with low literacy skills.

- **Short Term Objectives:** In the immediate phase, our primary focus revolves around laying a strong foundation for our initiative. We aim to swiftly gather a diverse array of speech datasets and refine our IVR service. To bolster accessibility, we will integrate a specialized model capable of recognizing numeric digits (1, 2, 3, and 4) into our voice server. This enhancement is specifically tailored to streamline navigation, benefiting individuals with lower literacy skills who rely on voice-based menus in languages such as Dioula, Moré, and Fula. Our immediate goal is to facilitate easier access to critical health information without necessitating advanced computer skills. Additionally, we are actively engaged in studies aimed at developing validated tools for measuring both health literacy and eHealth literacy in these languages.
- **Medium Term Goals:** Looking ahead, our strategy extends to a more comprehensive expansion. We're intensifying our efforts to gather language-specific data, not only in Dioula, Moré, and Fula but also across other local languages prevalent in Sub-Saharan Africa (SSA). This proactive step aligns with our commitment to continually enhance the efficiency and effectiveness of our IVR service. Additionally, we're broadening our activities to evaluate health literacy and eHealth tools among larger populations. This broader scope ensures our interventions are evaluated and tailored to cater to diverse needs.
- **Long-Term Vision:** Our long-term vision centers on fostering a holistic and user-centered experience. We're committed to integrating multiple language datasets into our IVR service to cater to the varied linguistic landscape across SSA, going beyond Dioula, Moré, and Fula. This ambitious vision underscores our dedication to perpetually improving the IVR system's accessibility for users with varying language skills. Furthermore, our ultimate objective is to expand our initiatives significantly, providing voice-driven digital tools specifically designed for low-literacy populations in SSA. This

General conclusion and perspectives

initiative aims to ensure equal access to crucial health information for all, irrespective of literacy levels or linguistic diversity.

Overall Strategy this strategic roadmap embodies a commitment to inclusivity, innovation, and equitable healthcare access. By prioritizing the inclusion of diverse languages and populations, we aim to break down barriers and provide equitable access to essential health information. Our strategy emphasizes a commitment to continuous enhancement, adapting our tools and services to evolving needs. Ultimately, by leveraging user-friendly, voice-controlled technologies, our goal is to bridge the healthcare gap, empowering underserved populations in Sub-Saharan Africa to make informed health decisions, irrespective of literacy limitations or linguistic backgrounds

List of publications

Published papers

Ouedraogo I, Some BMJ, Oyibo K, Benedikter R and Diallo G (2022). "*Using serious mobile games to improve health literacy in rural Sub-Saharan Africa: A literature review.*". Front. Public Health.

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I.Ouedraogo B.M.J Some Z.C.O Keita, E.Nabaloum, F.Bationo, R.Benedikter, G. Diallo,. "*Deploying a speech recognition model for under-resourced languages: a case study on dioula wake words 1, 2, 3, and 4*". 7th International Conference on Natural Language Processing and Information Retrieval, ACM Digital Library.

DOI: <https://doi.org/10.1145/3639233.3639345>

Papers under review

I.Ouedraogo M. J. Some, K.Oyibo R. Benedikter , et G. Diallo. "*Evaluating a phone based Interactive Voice Response system for reducing misinformation and improving malaria literacy*". Information Technology for Development.

I.Ouedraogo M. J. Some, R. Benedikter, et G. Diallo. "*Measuring Health and e-Health literacy among hospitalized diabetic patients in low-income countries: a case study in Guinea and Burkina Faso*". JMIR.

Conference presentations

I.Ouedraogo. "*Improving Health Literacy in Rural Communities in Africa using Mobile Technologies for an Inclusive Health Service*". Eighth International Conference on eDemocracy and eGovernment Quito, Ecuador from 28th to July 30th 2021.

I.Ouedraogo, M. J. Some, R. Benedikter, et G. Diallo. "*Improving health literacy in rural Africa through mobile phones: a systematic literature review*". 13th Health Informatics in Africa Conference in Kampala, Uganda from 18th to 22nd October 2021.

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I.Ouedraogo , R. Benedikter , R. Yameogo , G. Atemezing , I. Traoré , G. Diallo. "*Improving Covid-19 vaccine literacy among undergraduate students in Burkina Faso*". 10th International Conference on Healthcare Informatics (ICHI), Houston, Texas, USA June 26th-29th, 2023.

I.Ouedraogo , BMJ Some, ZC Oumar Keita, E Nabaloum , F Bationo, R Benedikter, G, Diallo. "*Deploying a speech recognition model for under-resourced languages: a case study on dioula wake words 1, 2, 3, and 4.*". 7th International Conference on Natural Language Processing and Information Retrieval, in Seoul, South Korea during 15th-17th December 2023.

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Measurement tool Unified Theory of Acceptance and Use of Technology

Table 2 – Unified Theory of Acceptance and Use of Technology (UTAUT)

Evaluation of 3-2-1 Mobile Service for Health Literacy

You are requested to participate in a research questionnaire titled "Assessing the 3-2-1 mobile service" aimed at evaluating the impact and factors influencing the acceptability of services and the technology feature preferences of internally displaced persons in Burkina Faso. This research is conducted as part of a PhD research work at Nazi Boni University. It will take you around 25 minutes to complete the questionnaire. Confidentiality rules will be respected in the survey, so do not indicate your name at any stage. Information to identify you personally will not be requested, and the information you share will not be shared with third parties and institutions. The data will be used in scientific publications, conferences, and training after analysis. Your participation in the survey is on a voluntary basis. You can choose not to answer the questions, you can give up after answering some of them. Your participation in this research will not have any sanctions nor will it bring you any benefit. If you have any questions about the research, you can contact the research team by e-mail or call them by phone.

E-mail address:.....

Telephone:

Informed Consent: I have been informed about the research

Demographic profile		
Gender		1)Female 2) Male
Age(years)		1)>18 2)18–24 3)25–50 4) 50+
Education		1) Uneducated 2) Primary school 3) High school
Income		1) >40 000 CFA 2) 40 000 CFA – 100 000 CFA 3) <100 000 CFA
Constructs	Questions	Answers
Perceived Usefulness	(1) Using the 3-2-1 Service improves my performance in seeking healthcare information.	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(2) Using the 3-2-1 Service makes it easy for me to seek healthcare information.	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(3) I find the 3-2-1 Service useful in seeking the healthcare information I need.	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
Perceived Ease of Use	(1) Learning to use the 3-2-1 Service is easy for me.	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(2) I found it easy to use the 3-2-1 Service	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.

Privacy Concern	(1) Using the 3-2-1 Service to seek healthcare information is secure.	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(2) Using the 3-2-1 Service to consult does not disclose my private information.	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(3) Government laws, regulations and legislations are important to guarantee the security and privacy of the 3 21 service	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
Perceived Trust	(1) I overall trust the services that are provided via the 3-2-1 Service.	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(2) I expect that the 3-2-1 Service to seek healthcare information is available for use without interruption of service.	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(3) level of service in adverse or hostile conditions (e.g. natural disasters, rural areas, and refugee camps).	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
Perceived Enjoyment	(1) Using a 3-2-1 Service is fun.	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(2) Using 3-2-1 service is enjoyable	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(3) Using 3-2-1 Service is entertaining	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
Perceived Compatibility	(1) I have the necessary knowledge and skills to use the 3-2-1 Service	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(2) I have used a system that has a similar feature to the 3-2-1 service	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree 5) Strongly agree.
	(3) I am familiar with this type of system 3-2-1 Service	1) Strongly 2) Disagree 3) Neither agree nor Disagree 4) Agree.) 5) Strongly agree.

Intention to Use

I will continue to use the 3-2-1 Service

- 1) Strongly
 - 2) Disagree
 - 3) Neither agree nor Disagree
 - 4) Agree
 - 5) Strongly agree.
-

Participants technology features preferences

Table 3 – Participants technology features preferences questionnaire

Exploring participants technology preferences questionnaire

You are requested to participate in a research questionnaire titled "Exploring participants technology features preferences" aimed at identifying preferences of internally displaced persons in Burkina Faso in using technology for health information. This research is conducted as part of a PhD research work at Nazi Boni University. It will take you around 25 minutes to complete the questionnaire. Confidentiality rules will be respected in the survey, so do not indicate your name at any stage. Information to identify you personally will not be requested, and the information you share will not be shared with third parties and institutions. The data will be used in scientific publications, conferences, and training after analysis. Your participation in the survey is on a voluntary basis. You can choose not to answer the questions, you can give up after answering some of them. Your participation in this research will not have any sanctions nor will it bring you any benefit. If you have any questions about the research, you can contact the research team by e-mail or call them by phone.

E-mail address:.....

Telephone:

Informed Consent: I have been informed about the research

Demographic profile

Gender	1)Female 2) Male
Age(years)	1)>18 2)18–24 3)25–50 4) 50+
Education	1) Uneducated 2) Primary school 3) High school
Income	1) >40 000 CFA 2) 40 000 CFA – 100 000 CFA 3) <100 000 CFA

Constructs	Questions	Answers
Language preference	In which language do you prefer to use the mobile?	(1) I prefer the French Language (2) I prefer More Language
Interface preference	What type of mobile interface do you prefer to use?	(1) I prefer text (2) I prefer Voice (3) I prefer Graphics/images
Type of design	Which types of design content do you prefer?	(1) Content with serious games (2) Content without serious games

Health literacy and eHealth literacy measurements questionnaires

Table 4 – Brief Health Literacy Screening and electronic Health Literacy Scale

Assessing Health Literacy and eHealth Literacy among diabetic patients

You are requested to participate in a research questionnaire titled "Assessing the Health Literacy and eHealth Literacy among hospitalised diabetic patients in Burkina Faso and Guinea " aimed at evaluating the patient's level of health literacy and digital health literacy. This research is conducted as part of a PhD research work at Nazi Boni University. It will take you around 15 minutes to complete the questionnaire. Confidentiality rules will be respected in the survey, so do not indicate your name at any stage. Information to identify you personally will not be requested, and the information you share will not be shared with third parties and institutions. The data will be used in scientific publications, conferences, and training after analysis. Your participation in the survey is on a voluntary basis. You can choose not to answer the questions, you can give up after answering some of them. Your participation in this research will not have any sanctions nor will it bring you any benefit. If you have any questions about the research, you can contact the research team by e-mail or phone. E-mail address: Telephone: Informed Consent: I have been informed about the research

Education	1) Uneducated 2) Primary school 3) High school
Income	1) >40 000 CFA 2) 40 000 CFA – 100 000 CFA 3) <100 000 CFA
Technology Access	1) Don't own a cell phone 2) Own a cell phone; 3) Own a smart-phone
Technology use	1) Never Internet use 2) Use sometimes for basic (social media such as WhatsApp) 3) Internet use regularly for information (including health information)

Brief Health Literacy Screening (BHLS) items	Questions	Answers
Question 1	How confident are you in filling in forms yourself?	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 2	How often do you get someone to help you read health information?	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 3	How often do you have problems getting information about your illnesses because of the difficulties you have in reading the health information?	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.

electronic Health Literacy Scale (eHEALS) items	Questions	Answers
Question 1	I know which health resources are available on the Internet.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 2	I know where to find helpful health resources on the Internet.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.

Question 3	I know how to find helpful health resources on the Internet.	1) Strongly 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 4	I know how to use the Internet to answer my health questions.	1) Strongly 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 5	I know how to use health information; I can use the health information I find on the internet to help me.	1) Strongly 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 6	I am good at assessing the health insurance companies I find on the internet.	1) Strongly 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 7	I can tell high-quality health resources from low-quality health resources on the Internet	1) Strongly 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 8	I feel confident using information from the internet to form an opinion about my health.	1) Strongly 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.

Table 5 – Malaria literacy, Knowledge, Attitude and Practice questionnaire

Evaluating health literacy, Knowledge, Attitude and Practice regarding malaria

You are requested to participate in a research questionnaire titled "evaluating malaria literacy " aimed at assessing malaria literacy among of internally displaced persons in Burkina Faso before and after using the 3-2-1 service. This research is conducted as part of a PhD research work at Nazi Boni University. It will take you around 25 minutes to complete the questionnaire. Confidentiality rules will be respected in the survey, so do not indicate your name at any stage. Information to identify you personally will not be requested, and the information you share will not be shared with third parties and institutions. The data will be used in scientific publications, conferences, and training after analysis. Your participation in the survey is on a voluntary basis. You can choose not to answer the questions, you can give up after answering some of them. Your participation in this research will not have any sanctions nor will it bring you any benefit. If you have any questions about the research, you can contact the research team by e-mail or call them by phone.

E-mail address:.....

Telephone:

Informed Consent: I have been informed about the research

Demographic profile

Gender	1)Female 2) Male
Age(years)	1)>18 2)18–24 3)25–50 4) 50+
Education	1) Uneducated 2) Primary school 3) High school
Income	1) >40 000 CFA 2) 40 000 CFA – 100 000 CFA 3) <100 000 CFA

Constructs	Questions	Answers
Knowledge (K)	(1) Malaria causes serious health consequences	True/false
	(2) Cause of malaria: Diet	True/false
	(3) Cause of malaria: Sun	True/false
	(4) Cause of malaria: Dirty environment	True/false
	(5) Cause of malaria: Lack of personal hygiene	True/false
	(6) Transmission of malaria: Female mosquito bites	True/false
	(7) Transmission of malaria: Bad spell or spirit, super-	True/false
	(8) Transmission of Malaria: Work Fatigue	True/false
	(9) Signs or symptoms of malaria: fever, headache,	True/false
	(10) To prevent malaria, sleep under a mosquito net	True/false
Attitude (A)	(11) Pregnant women should wait 2 days before visiting the hospital	True/false
	(13) Treatment of malaria is free for children under 5	True/false
Practice (P)	(14) Malaria prevention activities are only carried out	True/false
	(15) The best practice for malaria diagnosis and treatment is self-medication	True/false

System Usability Scale

Table 6 – System Usability Scale (SUS) questionnaire

Assessing the usability of an Interactive Voice Response system for COVID-19 literacy

You are requested to participate in a research questionnaire titled "Assessing the Usability of an Interactive Voice Response Service to improve COVID-19 literacy among high school students. This research is conducted as part of a PhD research work at Nazi Boni University. It will take you around 10 minutes to complete the questionnaire. Confidentiality rules will be respected in the survey, so do not indicate your name at any stage. Information to identify you personally will not be requested, and the information you share will not be shared with third parties and institutions. The data obtained will be used in scientific publications, conferences, and training after analysis. Your participation in the survey is on a voluntary basis. You can choose not to answer the questions, you can give up after answering some of them. Your participation in this research will not have any sanctions nor will it bring you any benefit. If you have any questions about the research, you can contact the research team by e-mail or call them by phone. E-mail address: Telephone: Informed Consent: I have been informed about the research.


Gender	1) Men 2) Women
Age	1) >10 2) 10 – 20 3) <20

System Usability Scale	Questions	Answers
Question 1	I think that I would like to use this system frequently.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 2	I found the system unnecessarily complex.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 3	I thought the system was easy to use.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 4	I think that I would need the support of a technical person to be able to use this system.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 5	I found the various functions in this system were well integrated.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 6	I thought there was too much inconsistency in this system.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 7	I would imagine that most people would learn to use this system very quickly.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.

Question 8	I found the system very cumbersome to use.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 9	I felt very confident using the system.	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.
Question 10	I needed to learn a lot of things before I could get going with this system	1) Strongly disagree 2) disagree 3) Neither agree nor disagree 4) Agree 5) Strongly agree.

Speech Data collection form

Figure 1 – Speech Data collection form



Formulaire de collecte de données

Projet de réalisation d'un modèle de reconnaissance vocale des chiffres 1, 2, 3 et 4 en langue dioula.

Pour remplir ce formulaire, veuillez cliquer sur le bouton " Record " et prononcer le chiffre demandé en Dioula. A la fin de la prononciation veuillez re-cliquer sur le même bouton pour arreter l'enregistrement.

NB: Vous pouvez appuyer sur le bouton " Play " qui vas apparaitre après l'enregistrement pour écouter votre vocal. Si vous voulez reprendre le vocal, il suffit de re-cliquer sur le bouton " Record ".

Prononcez " 1 " en langue Dioula *

Prononcez " 2 " en langue Dioula *

Prononcez " 3 " en langue Dioula *

Prononcez " 4 " en langue Dioula *

Merci pour le temps que vous avez consacré

Letters of Authorization for Conducting Research

Figure 2 – Letter of Authorization for Conducting Research

MINISTRE DE LA SANTE
DE L'HYGIENE PUBLIQUE ET DU
BIEN-ETRE

SECRETARIAT GENERAL

CENTRE HOSPITALIER
UNIVERSITAIRE SOURO SANOU
(CHUSS)

DIRECTION GENERALE

N° 2022/...../MS/SG/CHUSS/DG



BURKINA FASO

Unité - Progrès - Justice

Bobo-Dioulasso, le 28 JAN 2022

Le Directeur Général

H

Monsieur le Directeur de
l'Ecole Doctorale/ Sciences et
Techniques

BOBO-DIOULASSO

OBJET : Votre autorisation d'enquête

Monsieur le Directeur,

J'accuse réception de votre lettre relative à une autorisation d'enquête sur la thèse intitulée « **Améliorer la littératie en santé dans les zones rurales en utilisant les technologies de santé mobile pour des services de santé inclusifs** ».

Par la présente, je marque mon accord pour la réalisation de ladite enquête au profit **Monsieur OUEDRAOGO Ismaila**.

L'intéressé est invité à prendre attache avec le service concerné pour toute fin utile.

Vous en souhaitant bonne réception, je vous prie d'agréer, **Monsieur le Directeur**, l'expression de mes meilleures salutations.

Ampliations :

- Médecine.
- Chrono.



Dr Seydou BARRO./
Médecin de santé publique