BMC Public Health

RESEARCH

Open Access

A novel mobile application developed to improve dental care communication for Deaf and hard-of-hearing individuals

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Abstract

Background Deaf and hard-of-hearing (DHH) individuals frequently experience communication barriers in dental settings, resulting in delayed care and increased dental anxiety. Digital tools tailored to their linguistic and cultural needs are limited. This study reports the development and preliminary evaluation of MoDeHe (Mobile Dentist Hearing), a novel mobile application designed to improve communication and support dental management for DHH individuals.

Methods MoDeHe was fully developed by a multidisciplinary team, incorporating input from DHH consultants and dental professionals. The application consists of two main modules: (i) the *Patient Information* module, which provides educational sign language (SL) videos on oral health and common dental procedures, and (ii) the *Dental Examination* module, which includes SL-supported decision trees to facilitate communication during clinical examinations. A pre–post observational study was conducted with 39 DHH participants. Baseline measures included self-reported oral health status and items from the Modified Dental Anxiety Scale. Post-test measures assessed usability, satisfaction, communication preferences, and confidence attending dental care independently.

Results At baseline, 82.1% of participants had not visited a dentist in over two years and 89.7% perceived their oral health as poor. Communication barriers contributed to cancelled appointments (69.2%) and reliance on interpreters (61.5%). After interacting with MoDeHe, 97.4% reported satisfaction, 66.7% preferred the app as their primary communication facilitator, and 84.6% felt confident visiting the dentist without an interpreter.

Conclusions MoDeHe is an innovative mobile health (mHealth) solution developed specifically for DHH individuals to enhance communication and accessibility in dental care. Its offline functionality and culturally adapted SL content support scalability in diverse, resource-limited settings. Future studies should assess long-term clinical usability and adaptation to regional SL variations.

Keywords Digital health, MHealth, Dental care, Hearing impairment, Accessibility, Sign language

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Introduction

Deaf and hard-of-hearing (DHH) individuals represent a linguistically and culturally distinct population that frequently encounters systemic barriers to equitable healthcare access. While the term *"deaf"* (lowercase) refers to the audiological condition of hearing loss, *"Deaf"* (capitalized) is used by individuals who identify with the Deaf community, primarily use Sign Language (SL) for communication, and share a cohesive cultural identity [1, 2]. Globally, over 70 million Deaf individuals face persistent disparities in access to education and healthcare, with approximately 80% having never received formal education—a gap especially pronounced in low- and middle-income countries [3].

Access to healthcare for people with disabilities, including DHH individuals, is shaped by a complex and interrelated set of barriers encompassing financial constraints, provider-related factors, organizational and systemic limitations, physical and informational accessibility, and patient-related factors [4]. These barriers often interact, compounding inequities in access to timely, appropriate, and person-centered care. Within this multifactorial framework, communication barriers represent a critical determinant of healthcare access for DHH individuals, as ineffective communication can lead to misdiagnosis, reduced quality of care, and increased anxiety and stress [5–8]. These challenges are exacerbated by reliance on third-party interpreters, which may compromise privacy, and by healthcare systems that lack the time, training, or resources to provide inclusive communication. Consequently, DHH individuals are more likely to delay care, experience dissatisfaction with medical encounters, and receive suboptimal treatment [6–8].

Similar disparities are evident in oral and dental healthcare. DHH individuals frequently face limited access to oral health education, preventive services, and treatment, which adversely affects their oral health outcomes [9]. Alkhadhi et al. [10] reported high rates of dental caries, unmet treatment needs, and moderate gingival inflammation among hearing-impaired adults in Riyadh, indicating poor oral health–related quality of life (OHRQoL). Significant associations were observed between OHRQoL and oral hygiene practices, dental visit history, and clinical oral health indicators. Additionally, participants identified speech-related challenges as a major concern, highlighting the broader communicative and functional implications of oral health in this group [10]. A recent systematic review and meta-analysis synthesizing data from 29 cross-sectional studies similarly found fair oral hygiene, fair plaque status, and moderate gingival inflammation among hearing-impaired individuals [11]. These findings underscore the consistent pattern of compromised oral health in this population and emphasize the urgent need for accessible, culturally and linguistically tailored dental interventions.

In Türkiye, the National Disability Data System maintained by the Ministry of Family and Social Services reports 179,867 registered individuals with hearing impairments [12]. Despite this sizable population, the specific needs and experiences of DHH individuals in dental care remain poorly understood. Although several initiatives have sought to improve communication in clinical settings, substantial gaps persist in accessibility, sustainability, and cultural-linguistic appropriateness [13–15]. While SL remains the primary communication mode for many Deaf individuals, most healthcare professionals lack formal SL training and seldom have opportunities to develop or maintain fluency [8]. This communication gap limits direct interaction, particularly in time-constrained environments such as dental clinics. As a result, interpreter use often becomes the default, even when it may not be feasible or desirable due to concerns regarding privacy, immediacy, or continuity of care. The inability of most providers to communicate directly in SL highlights the need for alternative strategies that support accessible, independent communication for DHH individuals in clinical contexts.

Recent advancements in mobile health (mHealth) and artificial intelligence (AI) have shown promising outcomes in reducing healthcare inequalities, including those stemming from communication barriers. Innovations such as voice-to-text tools (e.g., Google Live Transcribe), AI-driven captioning systems, sign language avatars, and interactive mobile communication applications have emerged as accessible and scalable solutions [13–17]. For instance, *Odontoseñas* [13], developed specifically for dental care settings, and *DITE*™ [14], a general-purpose communication tool, have incorporated SL content and involved Deaf stakeholders in their design. While these technologies can reduce reliance on interpreters, enhance privacy, and improve patient engagement, their integration into dental care remains limited [13, 15]. Common challenges include issues of scalability, digital literacy, and workflow compatibility [13, 15]. Furthermore, qualitative studies reveal that many hearing clinicians continue to depend on lip reading or visual observation rather than employing culturally competent communication practices, reflecting persistent systemic gaps and insufficient training in Deaf-centered care [15]. Some Deaf users also perceive avatar-based or automated systems as impersonal or contextually insensitive, emphasizing the need for co-developed, culturally responsive, and user-informed design approaches [16, 17].

To address these gaps, we developed MoDeHe (Mobile Dentist Hearing), a novel mobile application supporting independent communication between DHH patients and

dental providers. The application was co-designed with DHH stakeholders and a multidisciplinary team including dental professionals, an audiologist, SL interpreter, and software engineers. MoDeHe incorporates:

1. Information for Patients module: SL videos and simplified content on oral health and dental procedures.
2. Dental Examination module: SL-based GIFs embedded in structured decision trees to support clear interaction during dental visits.

MoDeHe was designed to ensure offline usability, cultural and linguistic appropriateness, and ease of integration into routine dental practice. This study reports the development process of MoDeHe and evaluates its usability, acceptability, and perceived impact on communication and autonomy in dental care among DHH individuals.

Materials and methods

This study employed a single-group pre–/post-test observational design involving 39 DHH participants and was conducted as a preliminary feasibility and usability evaluation. The primary aim was to obtain initial user feedback and to explore short-term changes in self-reported communication-related outcomes following use of the application. Accordingly, the study was not designed to assess effectiveness or to support causal inference regarding the impact of the application.

As the present study was a preliminary investigation focused on feasibility and initial user feedback, no formal sample size calculation was performed. The number of participants was determined based on accessibility and practicality within the pilot framework and is consistent with similar feasibility studies reported in the literature. For instance, Chong et al. [14] conducted a comparable study with 18 participants, including both SL interpreters and Deaf individuals.

The study protocol was reviewed and approved by the University's Medical Research Ethics Committee (Approval No: 21-8t/72, Date: 03.09.2021) and conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

Development of the MoDeHe application

The mobile application, *MoDeHe*, comprised two primary modules: "Information for Patients" and "Dental Examination." Development was carried out by a multidisciplinary team including six dental specialists (5–20 years of experience), one Deaf individual, one hard-of-hearing individual, one Child of Deaf Adult (CODA), two computer engineers, one audiologist, and one SL interpreter. All team members contributed actively throughout all development stages.

Content development

Initially, six dental specialists collaboratively identified the most frequently encountered dental complaints based on clinical experience. Thirteen core issues were selected for inclusion in the *Dental Examination* module: toothache, loss of fillings, missing teeth, dissatisfaction with dentures, periodontal treatment needs, loose teeth, swelling and/or abscess, temporomandibular joint disorders, wisdom tooth-related problems, malocclusion, oral ulcers and/or soft tissue lesions, dissatisfaction with dental aesthetics, and dental and/or jaw trauma.

Subsequently, nine educational texts were prepared for the *Information for Patients* module, covering eight major dental specialties—Endodontics, Pediatric Dentistry, Periodontology, Prosthodontics, Restorative and Esthetic Dentistry, Oral and Maxillofacial Radiology, Oral and Maxillofacial Surgery, and Orthodontics—as well as dental and jaw trauma. To ensure accessibility, the content was written in concise and simplified language.

All texts and scenarios were reviewed iteratively through structured discussions by a multidisciplinary panel comprising one audiologist, one SL interpreter, one CODA, and three DHH individuals. Feedback was incorporated across multiple rounds of revision to enhance the clarity, cultural appropriateness, and accessibility of the application content. Based on their feedback, terminology was simplified, and text length reduced. The finalized content was translated into SL and recorded as videos by a SL instructor in collaboration with DHH participants. The videos were piloted with 30 DHH volunteers recruited from the Bornova, İzmir Association for Deaf Individuals, and revisions were made based on their feedback. These participants were not included in the evaluation sample, and their feedback was used exclusively for content refinement and usability improvements. The final application contained 114 SL videos: 67 in the *Dental Examination* module and 47 in the *Information for Patients* module. Recordings were produced in the Faculty of Communication studios, featuring a DHH narrator filmed from the waist up against a green screen to ensure optimal visibility of gestures and facial expressions.

Information for patients module

This module aimed to enhance oral health knowledge and awareness among DHH individuals by providing educational video content (Table 1, Fig. 1). The videos were uploaded to the official YouTube channel of Ege University Faculty of Dentistry (https://www.youtube.com/@egeuniversitesidishekimlig1694) and integrated into the mobile application via embedded links.

Table 1 Overview of educational video topics in the patient information module of the application

Endodontics	What is endodontics?
	What is root-canal treatment?
	When does a tooth need a root-canal treatment?
	How long does a root canal treatment take?
	How is the root canal treatment performed?
Pediatric Dentistry	What is pediatric dentistry?
	What does the pediatric dentistry department do?
	What is fluorine?
	What is fissure sealant?
	What is a space maintainer?
Periodontology	What is periodontology?
	Why should you visit the periodontology department?
	What does a periodontist do?
	What should you do if your teeth are loose?
Prosthodontic Dentistry	What does prosthodontic dentistry do?
	What are the types of dental prostheses?
	What is a fixed prosthesis?
	What is a prosthetic impression?
	Is follow-up required after the prosthesis is completed?
	How do you clean a dental prosthesis?
	What should you do if you grind your teeth?
	What is a removable prosthesis?
Restorative and Esthetic Dentistry	What is dental filling?
	When does a tooth need a filling?
	What is dental bleaching?
	How is the dental filling done?
Oral and Maxillofacial Radiology	When should you visit the radiology department?
	What services are provided by the radiology department?
	What is an X-ray?
Oral and Maxillofacial Surgery	When should you visit the surgery department?
	What is dental anesthesia?
	How is dental anesthesia administered?
	What to do with an impacted tooth?
	What is an abscess?
	What should you do if you have a jaw cyst or tumor?
	What is biopsy?
	What should you do if you have a jaw fracture?
	What should you do after jaw surgery?
	What is a dental implant?
Orthodontics	What is orthodontics?
	What is cleft lip and palate?
Dental Emergencies	What are dental emergencies?
	What should you do if your tooth is knocked out?

Dental examination module

This module was developed to facilitate communication between dentists and DHH patients. Decision trees were constructed for 13 dental complaints, incorporating multiple-choice questions and corresponding SL videos. This structure allowed DHH patients to express their symptoms more effectively, while structured headings guided dentists in interpreting responses (Fig. 2). All data were stored locally on the device, enabling full offline functionality.

Software development

User interface development and accesibility

The user interface was designed with a strong emphasis on accessibility to address the specific needs of DHH individuals. This process required a careful evaluation of visual clarity, interaction patterns, and multimodal communication elements. Particular attention was given to ensuring that all interface components supported intuitive navigation and minimized cognitive load.

A central design consideration was the integration and placement of SL videos, which function as a primary communication channel for many DHH users. These videos were positioned strategically to remain visible without obstructing task-related interactions. During development, SL videos also posed significant performance challenges. For example, GIF and Lottie formats produced substantial performance degradation, making them unsuitable. Consequently, optimized MP4 files were adopted to ensure smoother playback and improved responsiveness.

Interactive components—including buttons, icons, and navigation structures—were developed according to ergonomic design principles. This included ensuring sufficient element size, high-contrast color pairings, clear labeling, and consistent, predictable layouts to facilitate effortless use.

To further enhance usability, the interface adhered to established accessibility guidelines, prioritizing readability, simplified information flow, and adaptability to a range of device screen sizes. Collectively, these design decisions ensured that the application delivered an inclusive, user-friendly, and functionally coherent experience for DHH individuals.

The application was developed for both Android and iOS platforms using Flutter. Sign language videos and corresponding text descriptions were embedded across all relevant screens to support user comprehension. For offline functionality, device-based data storage was implemented using the SharedPreferences system.

Functional structure

The application serves two main user groups:

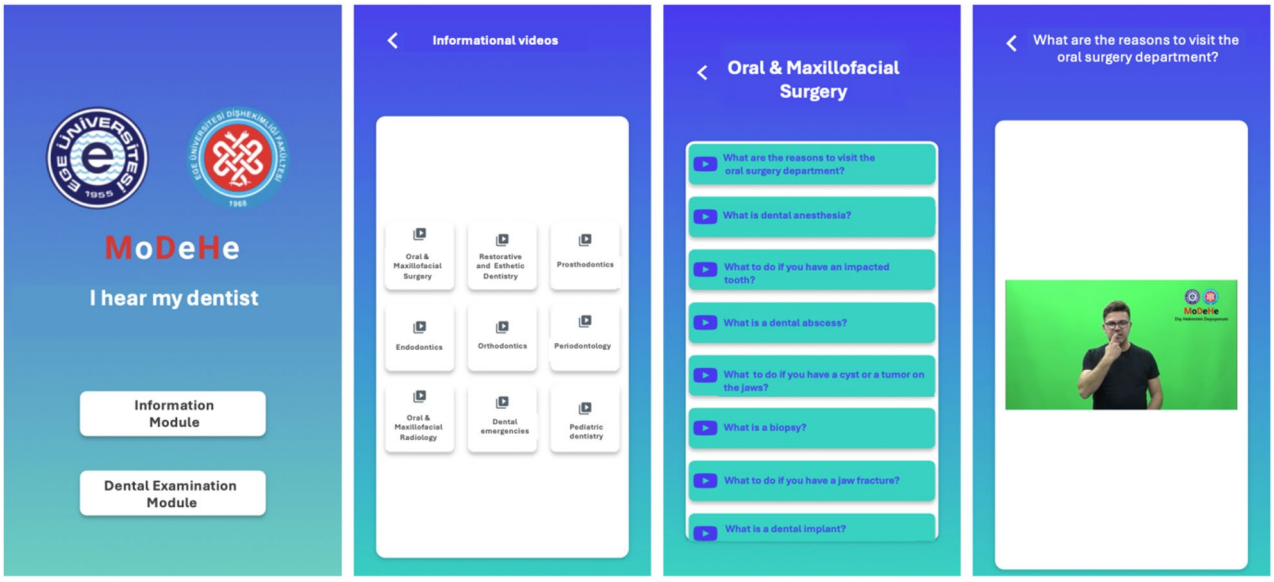

Fig. 1 Application interface and overview of the patient information module. Note: The original application is in Turkish; English translations were added to figures for international comprehensibility

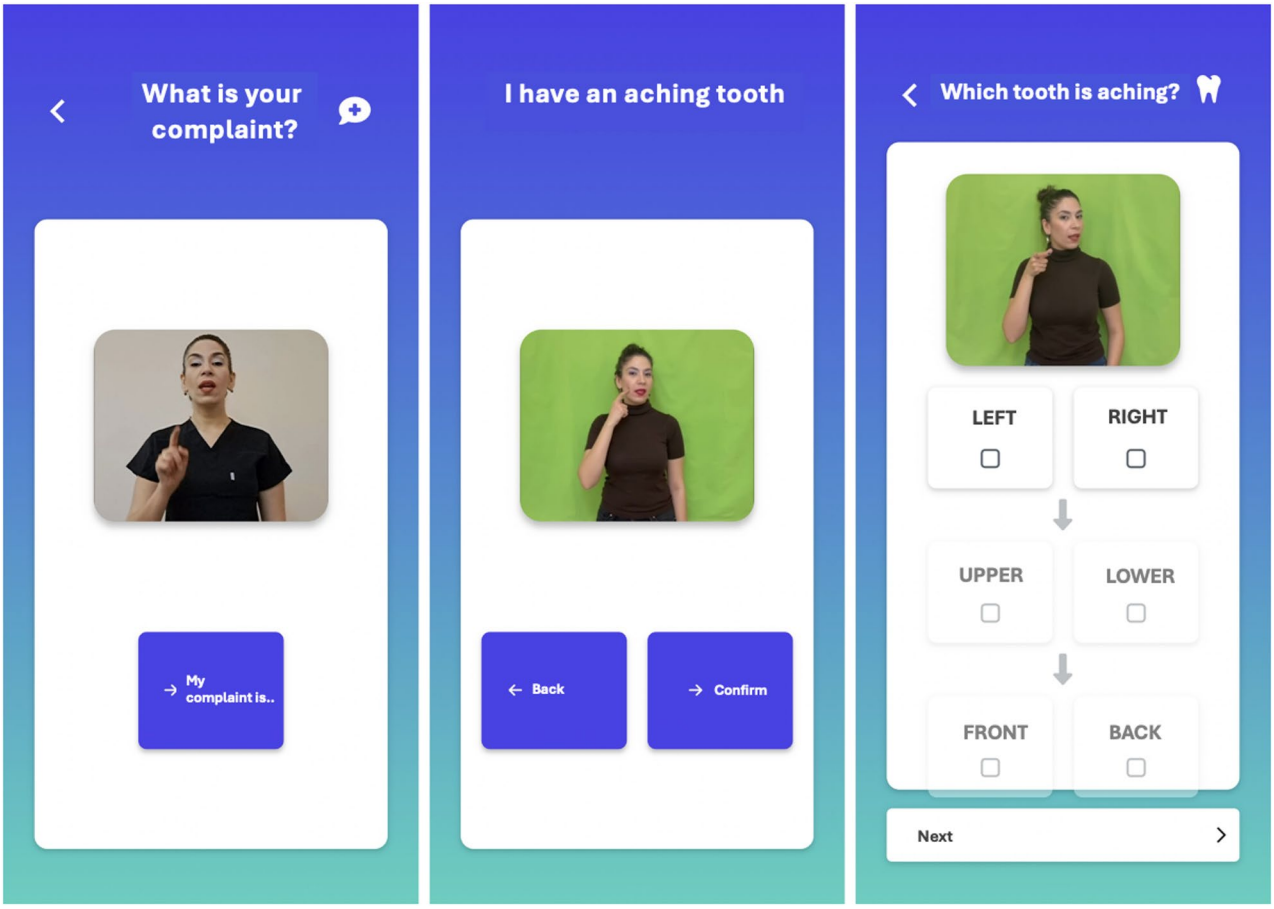

Fig. 2 Overview of the dental examination module. Note: The original application is in Turkish; English translations were added to figures for international comprehensibility

3. Dentists: Adding patients, viewing complaint summaries, conducting vitality/percussion assessments, reviewing radiographic history, and planning treatments.
4. Patients: Selecting complaints, providing detailed information, adding multiple symptoms, receiving sign language–supported guidance, and reporting radiographic history.

Use case processes

- Patient Registration: The dentist adds the patient to the system.
- Complaint Reporting: The patient selects symptoms through stepwise screens; the system generates a Complaint Summary.
- Treatment Planning: The dentist reviews the reported symptoms and selects appropriate treatment options.

Evaluation of application effectiveness

DHH individuals from the Bornova, İzmir Association for Deaf Individuals were invited to voluntarily participate. Eligibility criteria included being aged 18 years or older, having no visual impairment, and possessing basic SL communication skills. Written informed consent was obtained from all participants with SL interpreter support when necessary.

Participants attended appointments according to their usual preferences; some were accompanied by a family member or SL interpreter, whereas others attended independently. When necessary, supplementary communication strategies, including gestures and lip-reading, were used as part of customary communication practices.

Dental examinations were performed by three dental specialists (NEOO, ACU, EA) and were conducted primarily to contextualize and evaluate communication facilitated by the MoDeHe application, rather than to assess clinical oral health outcomes. The pre-test was administered prior to the dental examination and the post-test immediately afterward. The pre-test consisted of two sections: (1) three questions assessing participants' current oral health status and (2) four items adapted from the Modified Dental Anxiety Scale (MDAS) to measure dental anxiety and perceived barriers to accessing care. The Turkish adaptation of the MDAS, validated by Ilguy et al. [18], has demonstrated strong internal consistency and construct validity. The post-test included four questions aimed at assessing participants' satisfaction with the mobile application and identifying any shifts in their attitudes toward seeking dental care following its use.

Statistical analysis

Data were analyzed using SPSS 24.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including frequencies and percentages, were used to summarize participants' demographic characteristics, oral health status, previous dental care experiences, and post-test evaluations of the mobile application. As the primary aim was to assess usability and user perceptions, analyses were limited to descriptive statistics to provide a concise overview of responses in this preliminary evaluation.

Results

Among the 39 DHH participants, 53.8% were female and 46.2% male, with a mean age of 50.59 ± 8.90 years. Pre-test results indicated that 82.1% had not visited a dentist in over two years, and 89.7% reported poor oral health. Although 64.1% experienced normal stress levels during dental visits, 69.2% had cancelled an appointment due to communication barriers. Additionally, 48.7% stated that communication difficulties increased their stress, 59% reported dental anxiety, and 61.5% said they would not visit a dentist alone without a SL interpreter or assistant (Table 2). Post-test results showed that 97.4% of participants were satisfied with the software, and 66.7% preferred using the application to communicate with their dentist. Furthermore, 89.7% reported high satisfaction, and 84.6% felt they could attend dental appointments without an interpreter (Table 3). These findings indicate that the mobile application may have contributed to improved communication and facilitated better access to dental care for DHH individuals. By helping to reduce anxiety related to communication barriers and increasing participants' confidence in attending appointments independently, the application shows promise as a supportive tool for enhancing the dental care experience in this population.

Discussion

Healthcare professionals employ various communication strategies when interacting with DHH patients, including gestures, lip-reading, written communication, professional interpreters, and assistive technologies such as speech-to-text systems, communication applications, and video remote interpreting [8, 13–15]. Although these tools have improved accessibility, persistent barriers remain a major contributor to disparities in healthcare access for deaf individuals [16]. Inadequate communication can heighten anxiety, as patients may struggle to understand procedures or follow post-treatment instructions, issues that are also common in dental care. Recognizing these challenges, the World Health Organization (WHO) has emphasized the need for accessible communication strategies for people with hearing impairments,

Table 2 Participants' initial perceptions and experiences

Questions	Answers	*n* (%)
When was your last dental visit?	< 6 months	6 (15.4)
	6 months – 1 year	-
	1 year ago	1 (2.6)
	2 years ago	32 (82.1)
How do you rate your oral health?	Very good	4 (10.3)
	Good	10 (25.6)
	Average	14 (35.9)
	Poor	11 (28.2)
Have you ever canceled a dental appointment due to communication difficulties?	Yes	27 (69.2)
	No	12 (30.8)
How would you rate your stress level during the dental visit?	Not stressed	6 (15.4)
	Slightly stressed	5 (12.8)
	Moderately stressed	25 (64.1)
	Highly stressed	3 (7.7)
How would you rate your stress level related to communication difficulties?	Not stressed	5 (17.9)
	Slightly stressed	6 (15.4)
	Moderately stressed	20 (51.3)
	Highly stressed	6 (15.4)
Would you visit the dentist alone without a sign language interpreter or assistant?	Yes	15 (38.5)
	No	24 (61.5)
Are you afraid of dental treatment?	Yes	16 (41)
	No	23 (59)

Table 3 Participants' experience with the application

Questions	Answers	*n* (%)
Were you satisfied with the application?	Yes	38 (97.4)
	No	1 (2.6)
What is your preferred method of communication with your dentist?	SL interpreter	8 (20.5)
	Application (MoDeHe)	26 (66.7)
	Both	5 (12.8)
Would you feel confident going to the hospital alone if you had this application?	Yes	33 (84.6)
	No	6 (15.4)

including the use of SL, assistive hearing technologies, and systemic efforts to enhance communication equity in healthcare [3, 19]. However, implementation remains inconsistent, particularly in specialized fields such as dentistry, underscoring the need for scalable and culturally inclusive solutions.

The present findings support existing concerns regarding access to dental care among DHH individuals [9, 10]. In our study, 71.8% of participants experienced stress during dental visits, and 69.2% had canceled appointments due to communication barriers, confirming the central role of communication in restricting care access. While 59% reported no dental anxiety, 61.5% stated that they would not attend dental appointments alone, consistent with previous research linking communication challenges to stress in dental settings [7, 19]. Furthermore, 82% of participants reported that their most recent dental visit occurred more than two years ago. This finding is also consistent with previous studies showing that limited understanding of treatment procedures can increase uncertainty and insecurity, contribute to fear, and negatively impact long-term oral health outcomes in DHH populations [7, 20].

MoDeHe is the first mobile application in Türkiye specifically designed to support dental care for DHH individuals. At the global level, several applications have also been developed to facilitate communication between *Deaf* individuals and emergency personnel, pharmacists, and dentists [13, 21, 22]. To the best of our knowledge, only two applications have been specifically developed for dental practice: *OdontoSeñas* [13] in Chile and *Telesmile* [15] in Saudi Arabia, both aimed at overcoming communication barriers and improving oral health awareness. Additionally, *Deaf in Touch Everywhere* (DITE™) is a cross-platform mobile application that connects the Deaf community with off-site interpreters via secure video conferencing [14]. *Telesmile* primarily targets oral health education for blind and *Deaf* populations. Its two-way communication requires patients to write their chief complaint, share personal details, and upload

images, which may limit usability given the low literacy rates among DHH individuals [15]. In contrast; MoDeHe prioritizes visual and interactive tools, addressing the specific needs of the DHH community in a culturally and linguistically appropriate manner. The positive feedback received in this study reinforces the value of designing healthcare technologies that are both user-centered and locally adapted. After using the MoDeHe, 97.4% of participants reported satisfaction, and 66.7% preferred using the application to communicate with their dentists. High satisfaction with the application does not necessarily imply preference over all other communication methods. Some participants may value a combination of tools, such as SL interpreters, written communication, or family support, depending on the clinical context. In addition, the response options provided may have constrained participants' ability to express nuanced or conditional preferences. Additionally, 84.6% stated they would attend dental appointments alone without an SL interpreter or attendant. These results underscore the vital role of technological solutions in enhancing healthcare access for DHH individuals. However, in our study, satisfaction and confidence were assessed using single-item, self-reported questions, reflecting participants' perceived or hypothetical confidence rather than directly observed behavior or validated self-efficacy constructs. Consequently, although reported rates were high, these findings should be interpreted with caution and should not be extrapolated to indicate sustained behavioral change or broader clinical outcomes.

Similar to our findings Alkadhi et al. [10] reported that 73.6% of hearing-impaired patients said they would be willing to use smart phone applications to facilitate communication during dental appointments if their doctor recommended it. Deaf respondents rated *DITE*™ highly for performance expectancy, finding it useful, efficient, and helpful for booking interpreters. They noted reduced miscommunication with healthcare workers and expressed strong intent to use it regularly. Overall, they felt more confident seeking healthcare with *DITE*™ [14]. Campos et al. [13] reported that all Deaf participants (100%) were satisfied with their dental examination using the *OdontoSeñas*. The median Dental Visit Satisfaction Scale (DVSS) score increased from 21.3 to 29.3 with the use of the application. Fageeh et al. [15] designed a questionnaire to assess oral health knowledge, attitudes, and practices among blind and Deaf participants and to evaluate the *Telesmile's* efficacy. They found that participants' mean oral health knowledge was initially low but improved significantly after four weeks of use.

A key strength of this study is the user-informed, co-development process, involving collaboration with DHH individuals, a SL interpreter, and a multidisciplinary team to ensure culturally appropriate and accessible content. The application and SL videos were piloted and iteratively refined, enhancing usability and acceptability. Moreover, the study addresses a critical, under-researched barrier—communication in real-world dental care for DHH individuals—and provides preliminary evidence of feasibility and perceived user confidence to guide future research. In contrast, we acknowledge that the evaluation phase represents a preliminary assessment of usability and acceptability based on brief, self-reported measures, rather than a comprehensive or in-depth evaluation of participants' lived experiences or communication needs. A pre–/post-test observational design was employed to enable an exploratory comparison of participants' self-reported perceptions of communication quality and perceived accessibility of dental care before and after use of the MoDeHe application. This approach was intended to provide preliminary insight into short-term changes in user perceptions rather than to establish causal effects or effectiveness.

It is important to highlight that the usability and effectiveness of such tools may differ across diverse healthcare settings and user populations. Notably, SLs are not universal and may vary significantly between countries. Therefore, for digital health interventions like MoDeHe to be effective and culturally appropriate, the development of region-specific SL content and localization of interface elements are essential.

From a clinical perspective, integrating the MoDeHe application into routine dental workflows requires careful attention to practical considerations, including time constraints during appointments, chairside feasibility, and potential impacts on clinician workload. Effective implementation may also involve brief orientation or training for clinicians, accommodating variability in patients' communication needs, and supporting patient familiarity with digital tools, all of which are important to maintain smooth workflow and optimize the application's utility in real-world practice. Additionally, the offline functionality of MoDeHe enhances its potential usefulness in rural or underserved areas, where internet connectivity may be unreliable and access to professional SL interpreters is often limited [13]. These design features position the application as a scalable and adaptable communication aid that could be implemented across different linguistic and geographic contexts, helping to reduce communication-related disparities in dental and other healthcare services while supporting patient-centered care and clinician efficiency.

One limitation of the present study is the homogeneity of the sample, which may constrain the generalizability of the results to broader inter-institutional or national contexts. In particular, individuals with limited digital literacy may be underrepresented, potentially skewing perceptions of usability and accessibility. Additionally,

the short duration of the study and relatively small sample size preclude conclusions about the long-term impact of the mobile application on user behavior and sustained engagement. Future research should incorporate larger, more diverse, and randomly selected cohorts of DHH individuals to evaluate long-term outcomes, user retention, and adaptability across different healthcare environments.

The use of a single-group pre–/post-test observational design without a control group constitutes a significant limitation of this study. Such designs are susceptible to response bias and immediate post-test effects and do not allow causal attribution of observed changes to the intervention itself. In addition, the absence of adjustment for potential confounding factors and the reliance on short-term, self-reported outcomes limit the interpretability of the findings. The results should therefore be interpreted as indicative of perceived usability and acceptability rather than as evidence of effectiveness, causal impact, or sustained behavioral change.

An additional limitation relates to the inherent variability of real-world communication during dental appointments. Communication between DHH patients and clinicians is inherently multimodal, and it is neither feasible nor appropriate to restrict the use of natural strategies such as gestures, lip-reading [15, 23]. Although the application was designed to facilitate bidirectional clinical communication—including eliciting patients' complaints and explaining proposed treatment plans—it was implemented within routine dental interactions in which multiple communication modalities may have been used concurrently. These factors were not standardized or controlled and may have influenced participants' perceptions, thereby limiting the ability to isolate the application's specific contribution or mechanism of action. However, this reflects the inherently multimodal nature of communication and was therefore unavoidable.

Despite these limitations, the findings of this study underscore the positive impact of facilitating direct, linguistically appropriate communication on DHH patients' attitudes toward dental care. In light of these results, we advocate for the ongoing development, localization, and dissemination of mobile health applications designed to meet the specific needs of individuals with hearing impairments, thereby promoting equitable access to oral healthcare services.

Conclusion

The development and dissemination of innovative tools such as MoDeHe represent an important step toward improving equitable access to dental care for DHH individuals. This study demonstrates the potential of technology to facilitate independent, effective communication in dental settings, reducing reliance on interpreters and addressing existing disparities in healthcare access. The co-development process, involving DHH participants, a sign language interpreter, and a multidisciplinary team, ensured culturally appropriate and accessible content. From a clinical perspective, integration into routine dental workflows requires consideration of time constraints, chairside feasibility, clinician workload, and patient variability, while the offline functionality enhances scalability in underserved or resource-limited settings where internet access or professional interpreters may be limited. Although findings indicate high user satisfaction and improved perceived accessibility, the generalizability of results is limited by the sample's demographic characteristics, short-term evaluation period, and exploratory study design. Future research should include larger, more diverse populations, assess long-term outcomes, and explore regionally adapted versions of MoDeHe to support broader implementation. Overall, this study highlights the potential of digital health interventions to reduce communication barriers, support patient-centered care, and contribute to a more inclusive and accessible oral healthcare system.

Abbreviations

AI	Artificial Intelligence
CODA	Child of Deaf Adult
DHH	Deaf and Hard–of–Hearing
DITE™	Deaf in Touch Everywhere
DVSS	Dental Visit Satisfaction Scale
GIF	Graphics Interchange Format
MDAS	Modified Dental Anxiety Scale
mHealth	Mobile Health
MP4	MPEG–4 Video Format
OHRQoL	Oral Health–Related Quality of Life
SL	Sign Language
SPSS	Statistical Package for the Social Sciences
TMJ	Temporomandibular Joint
WHO	World Health Organization

Acknowledgements

We thank Soner Aslan and Volkan Yüce for their contributions to the sign language videos, the Ege University Faculty of Communication and EGETV staff for video editing support, Caglar Numanoglu for software development assistance, and Gülsemin Uysal Gültekin for expertise in Turkish Sign Language. We also acknowledge the Bornova Association for Deaf Individuals for their feedback and participation. Our participant in Figs. 1 and 2 gave written informed consent for her identifying images to be published in this study.

Authors' contributions

NEOO, EA, BOK, ACU, OB, EA2 conceptualized the study, conducted the investigation, was a major contributor to the preparation of the original draft, created the visualizations, and contributed to reviewing and editing the manuscript. NEOO, EA, BOK, ACU, OB, EA2 performed the formal analysis, participated in the investigation, and wrote the original draft. OB contributed to the formal analysis and writing of the original draft. EA, BOK, PPA contributed to the methodology, carried out the investigation, and assisted in writing the original draft. BOK provided supervision and contributed significantly to reviewing and editing the manuscript. PPA provided supervision and contributed to writing – review and editing. ES developed the software used in the study. AZO contributed to the conceptualization of the study. EA2 contributed to the methodology, supervision, project administration, and writing – review and editing. All authors read and approved the final manuscript.

Funding
This study was supported by the Scientific and Technological Research Council of Türkiye (TÜBİTAK) under the 1002 Short-Term Support Module (Project No: 123S371).

Data availability
Due to the sensitivity of the data and to protect the privacy of DHH participants, the datasets generated and analyzed during this study are not publicly available. All de-identified data generated or analyzed during the study are included within this published article.

Declarations

Ethics approval and consent to participate
The study design was approved by the Ege University's Medical Research Ethics Committee (Approval No: 21-8t/72, Date: 03.09.2021) and conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants.

Consent for pubblication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 7 November 2025 / Accepted: 6 January 2026
Published online: 13 January 2026

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