

Service Design of a Voice Rehabilitation System for Laryngectomees Based on Serious Games

Xiang Wang^{1*}
Xinyu Huang²
Zhizheng Zhang³

*Corresponding author

¹ Associate professor, Nanjing Institute of Technology, Nanjing, China, wangx1007@njit.edu.cn

² Nanjing Institute of Technology, Nanjing, China, wangx1007@njit.edu.cn

³ Lecturer, Nanjing Institute of Technology, Nanjing, China, zhizheng@njit.edu.cn

ABSTRACT

As the second most prevalent malignant tumor in the head and neck region in China, laryngeal cancer patients undergoing total laryngectomy face significant challenges in voice rehabilitation. The current traditional system suffers from three major dilemmas: uneven distribution of medical resources, poor training compliance, and delayed assessment. This study focuses on digital innovation pathways by developing a voice rehabilitation system based on serious games, aiming to overcome the inefficiency of rehabilitation through technological integration. This study employed product design and development methodologies: first, semi-structured interviews were conducted with seven typical patients, and the KJ method was applied to identify four core unmet needs — resource accessibility, training engagement, real-time assessment, and information interoperability. Subsequently, a tripartite design strategy integrating "gamified software + rehabilitation hardware terminal + management platform" was proposed and implemented, resulting in the completion of product and service prototypes. Additionally, a scale-based questionnaire survey was administered to 20 experts and users to validate the effectiveness of the service prototype. Empirical evaluation demonstrated an average score of 4.39/5 in the system functionality dimension, confirming its validity among experts and users. This study presents an innovative paradigm for speech rehabilitation in the digital healthcare era, not only improving the quality of life for 4.2 million laryngectomy patients but also providing a replicable design framework for the digital transformation of chronic disease rehabilitation.

Keywords: Service design, serious games, voice rehabilitation systems, interaction design, health application design.

INTRODUCTION

Laryngeal cancer is the second most common malignant tumor in the head and neck region, and its prevention, treatment, and rehabilitation represent urgent public health challenges in China (Yao,2024). According to statistics from the International Agency for Research on Cancer (IARC), there are approximately 214,000 new cases of laryngeal cancer globally each year, with 28.6% occurring in China and an annual growth rate of 3.2%, indicating an increasing trend in the number of laryngeal cancer patients in China (Bray *et al.*,2021). Currently, the incidence of laryngeal cancer in China exhibits dual disparities: geographically, the standardized mortality rate in urban areas (0.85 /100,000) is 37% higher than in rural areas (0.62/100,000); in terms of gender, the standardized incidence rate in males (2.69/ 100,000) is 7.7 times that in females (0.35 /100,000); and psychosocially, 85.7% of patients experience social withdrawal, with the incidence of depression being 6.2 times higher than before surgery(Liu *et al.*,2025). These data demonstrate that laryngeal cancer patients face significant challenges in both physical and psychological rehabilitation.

Similarly, the rehabilitation status of the 4.2 million laryngectomy patients in China remains far from optimistic, with only 23.6% having completed standardized speech rehabilitation training. This has resulted in a postoperative speech rehabilitation rate of less than 40%(Ye, 2023), fundamentally reflecting three structural challenges within the traditional rehabilitation system: first, uneven distribution of medical resources; second, poor adherence to training methods (Lazarou *et al.*,2024); and third, a lagging assessment system that fails to provide real-time feedback on outcomes. These challenges have led to a high dropout rate in rehabilitation, resulting in the permanent loss of recoverable speech function (Jiang ,2010).

Therefore, the aim of this study is to address the voice rehabilitation challenges faced by laryngeal cancer patients against the backdrop of rising global incidence rates. By developing a digital voice rehabilitation system based on serious games, we seek to resolve the triple failure of traditional esophageal voice training—namely, imbalanced resource allocation, insufficient primary healthcare support, and poor patient compliance. The core objective is to transform monotonous airflow control and articulatory organ coordination exercises into engaging virtual game tasks with emotional motivation and interactive features, thereby developing an intelligent training system incorporating serious games.

LITERATURE REVIEW

Current Research Status of Serious Game Theory

Serious games, as an interdisciplinary research field, have achieved a high degree of internationalization in both theoretical development and practical research. In this study, a keyword search for "serious game" was conducted on Google Scholar, yielding 3,190 English-language publications. The research topics span diverse domains such as educational psychology, human-computer interaction, and rehabilitation medicine, indicating that this field has established a relatively mature research framework within the international academic community. At the theoretical construction level, the primary distinction between serious games and recreational games lies in the specific functional objectives of serious games. Research indicates that the theoretical framework in this field primarily consists of four dimensions: the behavior-goal orientation mechanism requires each game segment to correspond to specific training objectives; the skill contextualization design transforms abstract skill development into concrete scenario-based tasks; the real-time feedback system reinforces behavioral modification through visualized data; and the structured reward system sustains users' long-term engagement motivation (Zheng *et al.*,2024). In the context of medical applications, serious games have evolved from early simulation training for healthcare professionals to patient rehabilitation interventions (Mertl & Frič,2019). Systematic literature reviews indicate that in the field of chronic diseases, glucose control games for diabetic patients can significantly improve self-monitoring rates. In the domain of neurorehabilitation, the U.S. Food and Drug Administration approved EndeavorRx as a therapeutic intervention for children aged 8–12 with attention deficit hyperactivity disorder. This game underwent seven years of testing, including five clinical trials involving over 600 affected children, and was ultimately proven to effectively enhance attention (Akili Interactive Labs,2025). Notably, research targeting elderly populations has demonstrated that integrating swallowing function training with virtual restaurant scenarios can substantially improve training completion rates. These studies provide insights for the application of serious games in voice rehabilitation training for laryngeal cancer patients, while also highlighting the need to address digital divide challenges among older adults and medical efficacy concerns.

The Value of Esophageal Speech Rehabilitation Training from the Perspective of Serious Games

In the context of current speech rehabilitation services, the integration of serious games offers targeted solutions to address the shortcomings of traditional rehabilitation approaches: 1) Overcoming adherence challenges in training by activating the dopamine reward system through virtual achievement systems and game-level unlocking mechanisms, thereby enhancing user motivation for learning. 2) Mitigating healthcare resource disparities—specifically, leveraging online learning platforms and AI assistance to ensure equitable access to professional guidance for patients in remote areas, reducing the cost of speech rehabilitation training, while alleviating the workload of speech therapists and improving their service efficiency. 3) In the dimension of social function reconstruction, virtual technology eliminates vocal shame by providing patients with digital social identities and enhances user participation rates in social activities through interactive gaming. Therefore, esophageal speech rehabilitation training from the perspective of serious games refers to a novel model that incorporates gaming as a design element into the rehabilitation process, transforming traditional training methods based on immersive and goal-oriented gaming features. This model selects compatible game mechanics tailored to the biomechanical characteristics of esophageal speech training—for instance, converting vocal effect control into virtual level unlocking conditions, enabling patients to unconsciously achieve rehabilitation goals while completing esophageal airflow regulation tasks. Integrating the educational objectives of serious games with the convenience of online learning, this approach represents a training paradigm that combines educational value, contextual relevance, interactivity, and gamification.

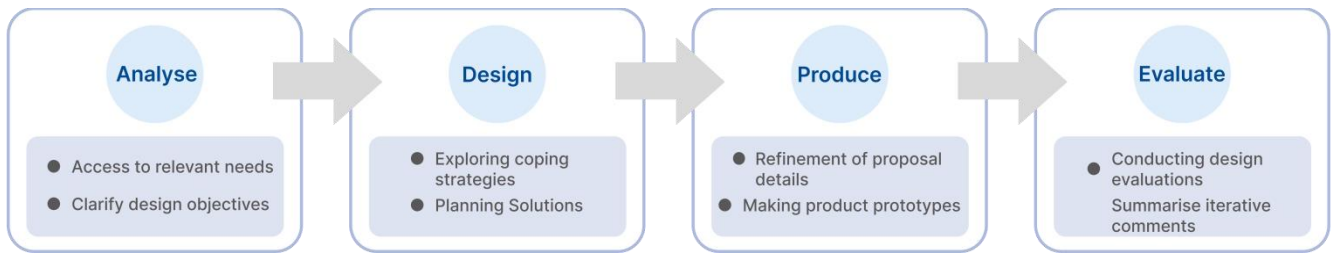
RESEARCH DESIGN AND PRACTICE

Research Methodology

In the field of design, product design is a creative activity that spans from conceptualization to implementation. Designers utilize various tools, methods, knowledge, and experience to generate effective solutions through integration and innovation. The essence of product design lies in creation. Through the accumulation of practical experience in product design, designers have summarized numerous relatively mature design thinking approaches (Duan *et al.*,2020). These serve as the "behavioral logic" guiding the transition from technology to product, ensuring that product design proceeds within a systematic and clear framework (as shown in the Figure 1). This study will explore from the following four steps (Lloyd & Oak,2018):

- 1) User Needs Analysis: The analysis phase serves as a critical foundation in the design process. During this stage, designers systematically observe and analyze relevant elements to identify design requirements and objectives, while exploring evaluation criteria for design solutions.
- 2) Design Strategy: The design phase is the comprehensive stage of the design process, where designers complete the main content of design innovation. By comprehensively analyzing various elements related to product objectives during this phase, designers utilize methods such as brainstorming to conceive design ideas based on their knowledge and experience, thereby clarifying problem-solving strategies.
- 3) Design and Development: The development phase represents the tangible output of the design process, where the design scheme is implemented in practice. This stage requires careful consideration of more detailed design aspects to ensure feasibility, thus further refining and optimizing the design scheme generated in the previous phase.

4)Design Evaluation: The evaluation phase serves as the culmination and refinement of the design process, assessing the applicability of the proposed design solution. Based on evaluation feedback, it involves redefining design strategies or improving design methodologies to generate superior solutions.



Source: Author created

Figure 1: Research Methodology/Process

User Requirement Analysis

User selection

Semi-structured user interviews represent a qualitative research method that combines flexibility with structured approaches, widely employed in social sciences, market research, and user needs exploration. Strauss (1987) proposed that theoretical "saturation" is achieved when coding analysis no longer yields new concepts or categories, indicating the inability to develop further novel categories or concepts. This study utilized semi-structured user interviews to investigate the needs of seven patients and their family members (information saturation confirmed), with participant demographics presented in the table 1. Some patients are shown in Figure 2.

Table 1: User Information

No.	Name	Disease type	Reason for excision	Training Phase	Rehabilitation Effect Rating
1	Mr. Chen	Laryngeal cancer	Squamous cell carcinoma	Completed	Fully recover
2	Mr. Wang	Laryngeal cancer	Adenocarcinoma	incomplete	During training
3	Ms. Wang	Hypopharyngeal cancer fatigue	Tumors in the posterior region of the ring	Completed	Fully recover
4	Mr. Liu	Laryngeal radiation necrosis	Necrosis of laryngeal tissue	Completed	Poor recovery
5	Mr. Song	laryngophthisis	Infectious diseases	Incomplete	During training
6	Mr. Lin	Uncontrolled benign tumor in the throat	Massive vascular malformation compresses the trachea	Completed	Poor recovery
7	Mr. Jiang	necrotic laryngitis	Bacterial necrotizing pharyngitis	Completed	Fully recover

Source: Author created



Source: Author created

Figure 2: Interview records

Interview content and needs insights

In this study, through in-depth interviews with seven users, representative responses for each question were selected, organized, and summarized to identify patient needs during the voice rehabilitation process. The results are presented in the Table 2 below.

Table 2: Interview Content and Needs Insights

Question	Answer	Requirement Insights and Issues
Q1: What training methods did you adopt during rehabilitation?	It all depends on the Speech Rehabilitation Department of the municipal hospital. Every Tuesday afternoon, I go to the training room, where the therapist teaches me to use the "air swallowing method" and the "ah" sound. However, last week the therapist was transferred, and the new intern couldn't even clearly explain how to control esophageal vibration... Now I can only repeatedly listen to the previously recorded instructional audio, but there's no one to correct whether my movements are accurate.	Limited availability of adaptive rehabilitation resources
	I started practicing three months after the surgery. Initially, it was a rehabilitation program arranged by the hospital's rehabilitation department, with two sessions per week, where a speech therapist guided me step-by-step to practice belching and air retention. However, relying solely on hospital sessions was insufficient, so I purchased a copy of the "Esophageal Speech Training Manual" from a patient support group and practiced swallowing exercises daily in front of a mirror, following the illustrated instructions.	Individuals cannot assess the accuracy of their pronunciation during self-practice.
	Sigh, the doctor told me to practice at the community hospital after discharge, but no one there knew how to teach me. My son bought me an electrolarynx, but I find the robotic voice embarrassing—I still want to speak naturally. Later, an elderly neighbor, Old Zhang, who also had a laryngectomy, took me to a sign language class at the senior university. But the teacher said, "We only teach the deaf here; you should contact the Disabled Persons' Federation." Now, I rely entirely on online video lessons from a nonprofit organization via WeChat, but the connection is so unstable that sometimes I get so frustrated I end up in tears...	Lack of authoritative guidance
Q2: What problems have you encountered during your rehabilitation?	The hospital mentioned that the Disabled Persons' Federation offers free courses, but they only hold two sessions per month, both on weekday mornings. Taking leave three times would get me fired from the construction site. Later, I inquired about private rehabilitation institutions, where each session costs 300 yuan—way too expensive!	The cost of rehabilitation resources is excessively high.
	I can't even pronounce a single syllable correctly! The doctor told me to "swallow air and quickly contract my abdomen," but every time I either swallow the air into my stomach and can't burp, or the airflow rushes out and turns into a farting sound. After practicing for two months, I'm still stuck on the "ah—" sound, while Old Liu in the next bed could say "drink water" by the third day.	Individuals exhibit significant physiological variations, making uniform teaching methods unsuitable.
	More than five words and it's a "power outage"! For example, when saying "I take the subway home," I run out of breath at the word "subway." The doctor taught me to press my neck with my fingers for support, but as soon as I let go, I can't continue. Now, talking to people is like sending a telegram: "I... want... to... register... for... ENT..."—each word requires a fresh breath.	Lack of progressive vital capacity training protocol
Q3: Can you persist in learning during rehabilitation?	For the first three months, I practiced for two hours every day without fail, but even now I can only produce monosyllabic sounds like "ah" and "oh." My granddaughter says it sounds like "an old cow mooing," and the neighbors think I'm chanting scriptures at home...	Lack of positive reinforcement for incremental progress
	To be honest, it's really hard to persist. The doctor taught me to use esophageal speech, but during practice, I can't tell whether I'm doing it correctly or not. Sometimes after practicing for a long time, my throat hurts, but my family still says the sound isn't right, which is particularly discouraging. If there were a machine that could give real-time feedback like "this vocalization is correct" or "insufficient airflow," it would probably make things much easier.	Lack of auxiliary equipment for monitoring pronunciation
	My daughter keeps urging me to practice every day, but she doesn't understand the proper techniques at all! Once, she pressed hard on my stomach to "help circulate the qi," only to force the qi up into my nasal cavity and make me blow a snot bubble... Now, whenever I hear her say, "Mom, try again," I just want to hide.	Interference of Kin Goodwill in Professional Training Rhythms
	During my weekly visits to the therapist, he would record my pronunciation using audio equipment and compare it with previous recordings. This was the only "scientific" evaluation method, but the intervals between follow-ups were too long, making self-practice	Unable to guide daily training adjustments

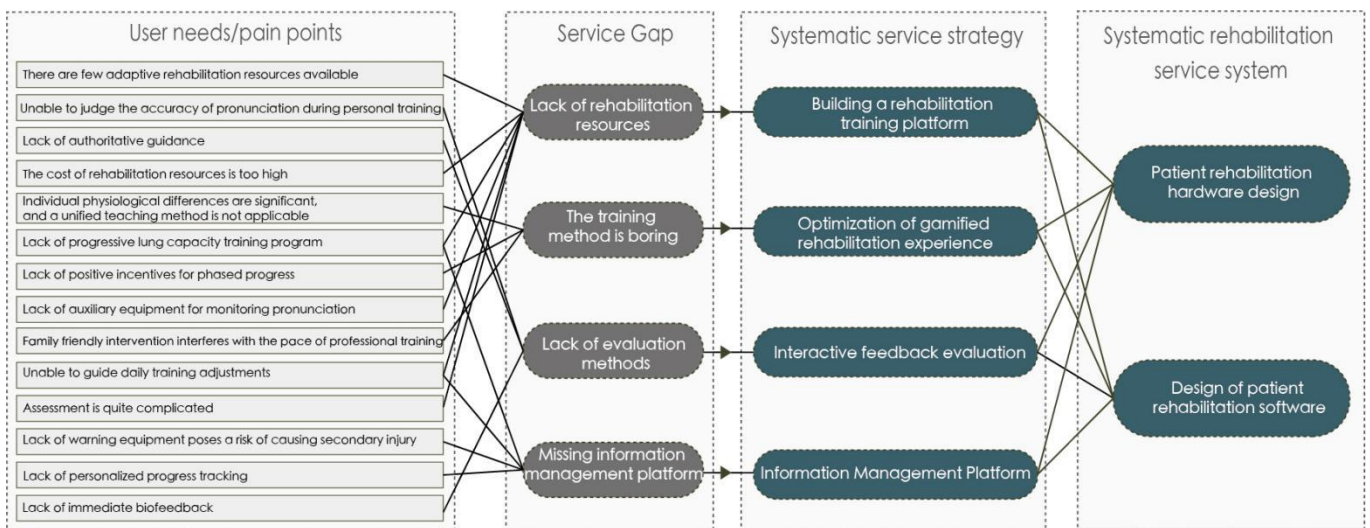
Q4: What methods do you currently use to evaluate training progress?	in between feel like groping in a "black box." Once, I thought I had practiced well, but the follow-up revealed that my method was incorrect, wasting three weeks of effort.	
	Generally, patients still need to go to the hospital for evaluation and training, but this process is relatively inconvenient due to the long distance from home. Sometimes, consultations are conducted via phone calls or WeChat video calls to seek medical advice from doctors.	Evaluation is relatively cumbersome.
	I attempted to record with my smartphone, but it was difficult to discern subtle differences during playback. The most frustrating part was that despite practicing with great effort, esophagoscopy revealed mucosal hyperemia. If there were a device capable of providing real-time warnings about "excessive pressure," such injuries could be avoided.	The lack of warning devices poses a risk of secondary injuries.
Q5: What methods do you currently use to evaluate training progress?	I hope it can function like a "coach" with three key features: first, real-time error correction, providing immediate auditory or vibrational feedback such as "airflow too weak" or "incorrect position" during practice; second, progress visualization, ideally generating daily training reports, for example, "today's success rate improved by 10% compared to yesterday"; third, safety protection, automatically halting training and issuing an alert when my actions risk harming the esophagus.	Lack of personalized progress tracking
	The product must be simple and user-friendly! I am 70 years old, and it would be best if the status could be directly determined through color changes.	Lack of real-time biofeedback
	I want a device with few buttons and loud sound, just like an old-fashioned radio, preferably capable of providing real-time feedback during detection.	

Source: Author created

Design Strategy

Pain point summary and service strategy

Based on user interviews, this study systematically analyzed user needs and summarized them using the KJ method (Scupin,1997). From 14 specific pain points in voice rehabilitation, the study distilled four core service gaps: lack of rehabilitation resources, monotonous training methods, absence of evaluation methods, and the need for an information management platform. To address these service gaps, the study proposed targeted systematic service strategies, including the construction of a rehabilitation training platform, gamification of rehabilitation experiences, interactive feedback evaluation, and the development of an information management platform, as illustrated in the Figure 3.

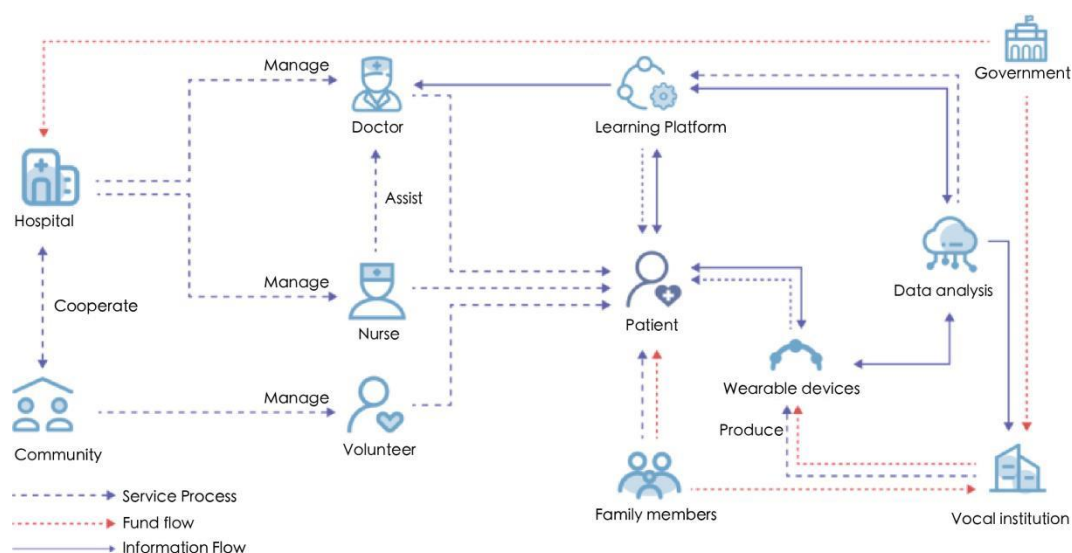


Source: Author created

Figure 3: Pain Point Summary and Service Strategy

Service Model

Based on previous research, this study aims to develop a comprehensive service system, with the core focus on establishing a gamified esophageal speech rehabilitation platform. It completes the "hardware + software + gamified experience" design scheme, providing digital information support for both medical professionals and patients, as well as rehabilitation institutions. This system constructs a full-cycle rehabilitation service framework encompassing assessment, training, and monitoring. By integrating multi-party resources and intelligent technologies, the ecosystem achieves a closed-loop service process from functional evaluation to rehabilitation outcome tracking, forming a sustainable and optimizable voice rehabilitation training model (as shown in Figure 4).



Source: Author created

Figure 4: Service System Diagram

Design Strategy

Building upon previous research, this study further categorizes the commonly used design elements in serious games—such as game genres, themes, rules, interaction modes, and design styles—into four design dimensions based on the actual research context: game planning, game interaction, visual presentation, and training hardware terminals. Design strategies are also proposed accordingly (as shown in Table 3).

Table 3: Design Strategy

Design latitude	Design Strategy
Game Designer	<ul style="list-style-type: none"> ● First, it is essential to define user requirements. Since laryngectomy patients are often elderly, the gamified system should prioritize simplicity and intuitiveness while incorporating effective motivational mechanisms. ● Core training objectives should focus on breath control, laryngeal muscle training, and pronunciation accuracy. ● Game mechanics could integrate these elements—for example, using breath control to manipulate in-game actions (e.g., blowing to move objects or sustain virtual flames). ● Level Design must adopt a progressive structure, gradually increasing difficulty while providing real-time feedback (e.g., visual cues for correct techniques) and reward systems (e.g., badges or progress milestones) to sustain engagement. ● Data tracking is critical to monitor performance metrics (e.g., breath duration, accuracy), enabling adaptive difficulty adjustments and sharing insights with medical teams.
Game interaction	<ul style="list-style-type: none"> ● Input methods must accommodate non-verbal interactions, such as gestures, touch, breath sensors, or EEG devices, tailored to physical limitations. ● Feedback mechanisms should combine visual (e.g., progress bars), auditory (e.g., success tones), and haptic (e.g., vibrations for correct actions) channels. ● Interfaces must prioritize simplicity, minimizing complex inputs, and allow customization (e.g., adjusting sensor sensitivity or feedback intensity).
visual representation	<ul style="list-style-type: none"> ● Interfaces should be clean and uncluttered, with high-contrast colors to aid users with impaired vision. Dynamic elements (e.g., animations) must be subtle to avoid sensory overload. ● Themes could center on nature (e.g., calming landscapes) or daily-life scenarios (e.g., virtual conversations) to enhance relatability. ● A virtual mentor (e.g., an animated guide) could provide encouragement and emotional support.
Training hardware terminal	<ul style="list-style-type: none"> ● Devices must be portable and home-friendly, integrating sensors like breath detectors, EMG sensors, or pressure-sensitive pads. ● Materials should ensure safety and comfort (e.g., hypoallergenic, ergonomic designs). ● Seamless software-hardware integration is crucial for real-time data syncing and cloud-based storage to track long-term progress. ● Cost-effectiveness should be addressed through partnerships with healthcare institutions to subsidize device expenses.

Source: Author created

DESIGN AND DEVELOPMENT OF SERIOUS GAMES FOR VOICE REHABILITATION IN LARYNGECTOMY PATIENTS

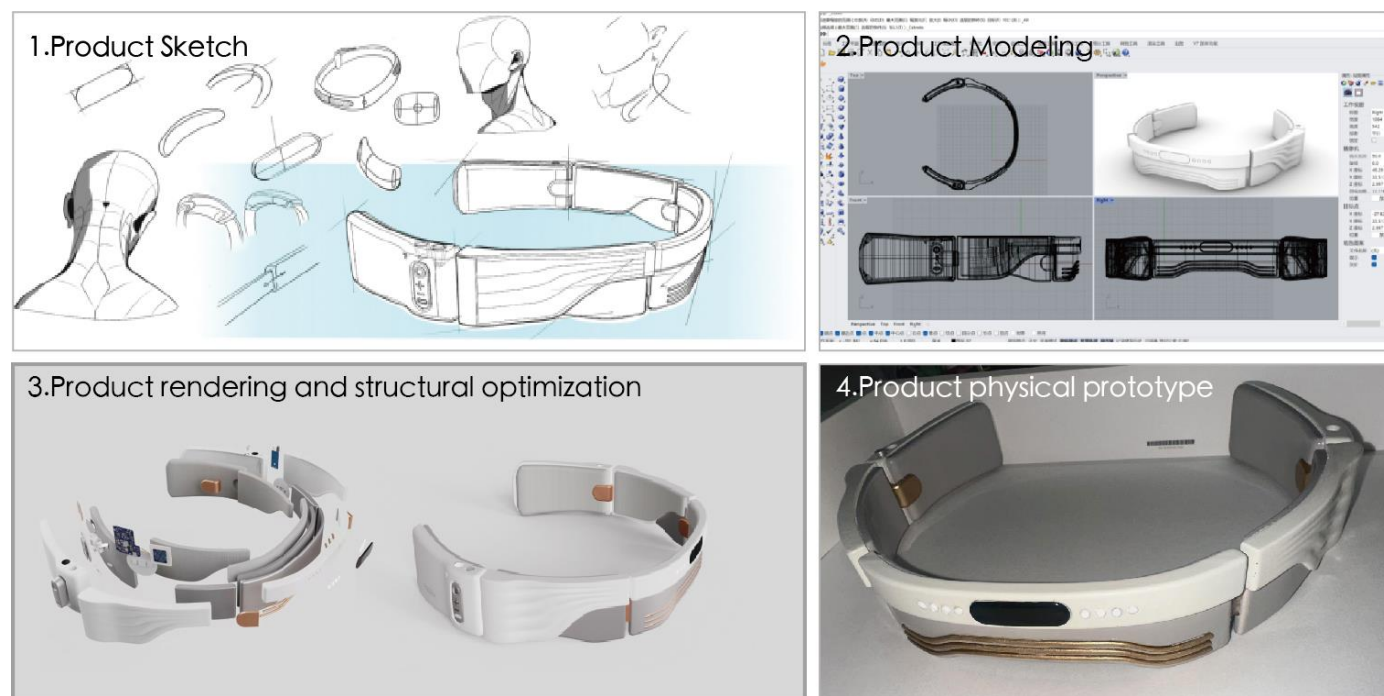
Product Functionality

The intelligent rehabilitation system developed in this study adopts a collaborative architecture of hardware terminals and mobile platforms to assist laryngectomy patients at different learning stages in conducting scientific voice rehabilitation training in home settings. It employs design and technological approaches to ensure training safety and incorporates a monitoring and evaluation module, thereby reducing secondary injuries caused by voice rehabilitation. The hardware terminal, serving as the carrier for vocal rehabilitation training, primarily encompasses the following functionalities: 1) audio processing and noise reduction; 2) medical interface capability; 3) ergonomic and compatibility features; and 4) sound signal monitoring, among others. As a medium for virtual game interaction, the voice rehabilitation gaming software primarily features the following functions: 1) Task mapping for voice rehabilitation, which transforms core training actions into gradient-based gaming tasks; 2) Multimodal interactive feedback; 3) Gamification design, among others. The management app serves as a communication node between hardware, users, and physicians, primarily providing the following functions:

1) An intelligent training guidance system that dynamically adjusts training difficulty based on user assessment results; 2) Knowledge acquisition and information retrieval; 3) A platform for patient-physician communication; 4) Optimized voice rehabilitation solutions; 5) Monitoring of voice rehabilitation data; 6) Multi-terminal information exchange among patients, caregivers, and physicians.

Hardware Terminal Development

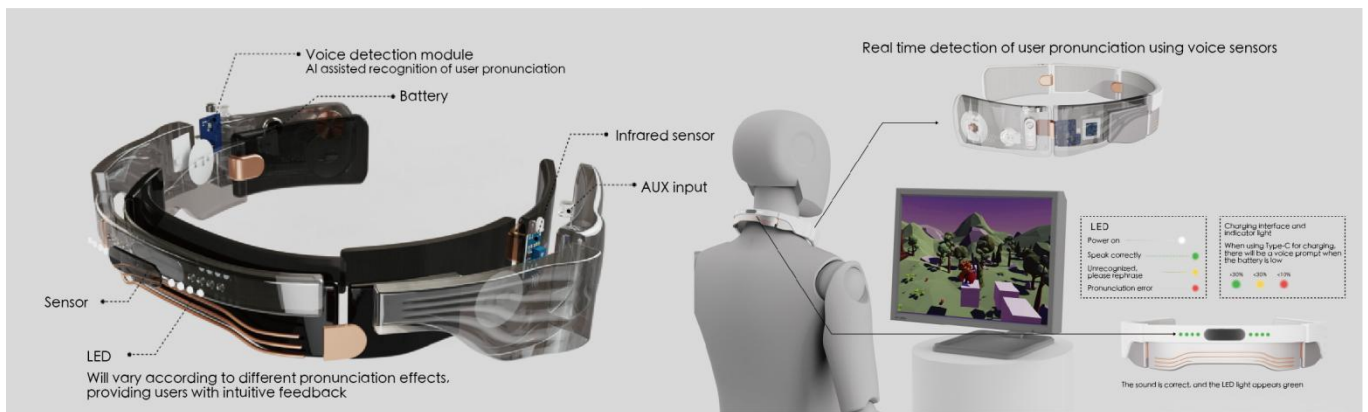
Based on the above analysis, this study deduced the appearance and structure of the hardware terminal, utilized Rhino software for modeling and structural design, and ultimately completed the prototype design. The steps are illustrated in the Figure 5.



Source: Author created

Figure 5: Hardware Terminal Development Steps

The hardware terminal in this study (as shown in the Figure 6) is used in conjunction with serious games, following a standardized procedure as follows: The user wears the device on the esophageal vibration zone of the neck. During gameplay, the hardware terminal automatically calibrates via Bluetooth connection to the computer. Throughout the training session, the terminal monitors in real-time and provides immediate biofeedback through LEDs: a green light is displayed when target parameters are met, activating positive reinforcement in the game; a red-light warning and tactile vibration are triggered when parameter deviation exceeds 15%; and a yellow light is displayed with game suspension awaiting re-input when sound recognition fails. The training process constitutes a closed-loop feedback cycle of "physiological signal acquisition—game behavior mapping—feedback stimulation (visual, auditory, tactile)."



Source: Author created

Figure 6: Product Structure and Usage Diagram

Software Design — Construction of the Game-Based Rehabilitation System

This study designed a staged and progressive game-based voice rehabilitation software DEMO, which enables quantitative esophageal function recovery training in a multimodal interactive environment. The study elaborates on aspects including game level and gameplay design, as well as user interface development.

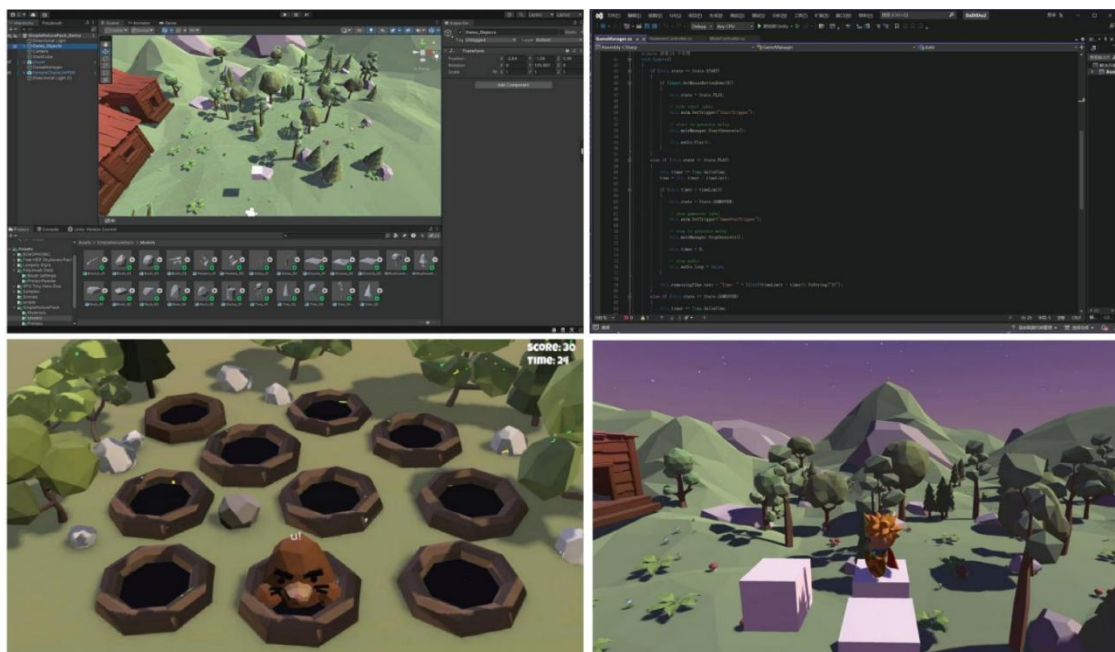
Rehabilitation game levels and specific gameplay settings for complex sounds

The voice rehabilitation game consists of two phases:

- 1) The basic vocalization training phase employs a jumping challenge mode (Level of jumping). Patients control the duration and loudness of esophageal phonation to manipulate character jumps, where vocal loudness determines jump height. Stable airflow pressure enhances the patient's ability to overcome obstacles, guiding them to proficiently control the pressure and vibration rhythm of the esophageal air sac.
- 2) The language application practice phase features a pronunciation striking game. Patients must correctly articulate target words upon hearing them. An AI speech enhancement module improves esophageal voice recognition through formant compensation and noise isolation technologies. Correct pronunciation triggers dynamic virtual hammer strikes and socially motivating auditory feedback, while incorrect pronunciation prompts the user through vibration cues.

Design of the compound sound rehabilitation game interface

This study constructs a hierarchical interaction system based on game interface design developed with the Unity engine, centered on user-centric and gamified functionality principles, while incorporating the cognitive characteristics and rehabilitation goals of laryngectomy patients (as shown in the Figure 7).

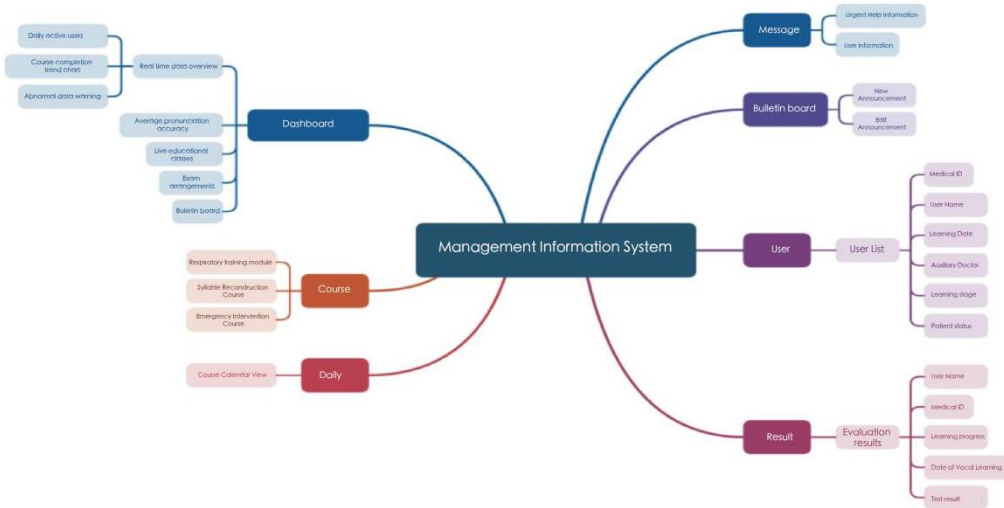


Source: Author created

Figure 7: Interface Design of Vocal Rehabilitation Game

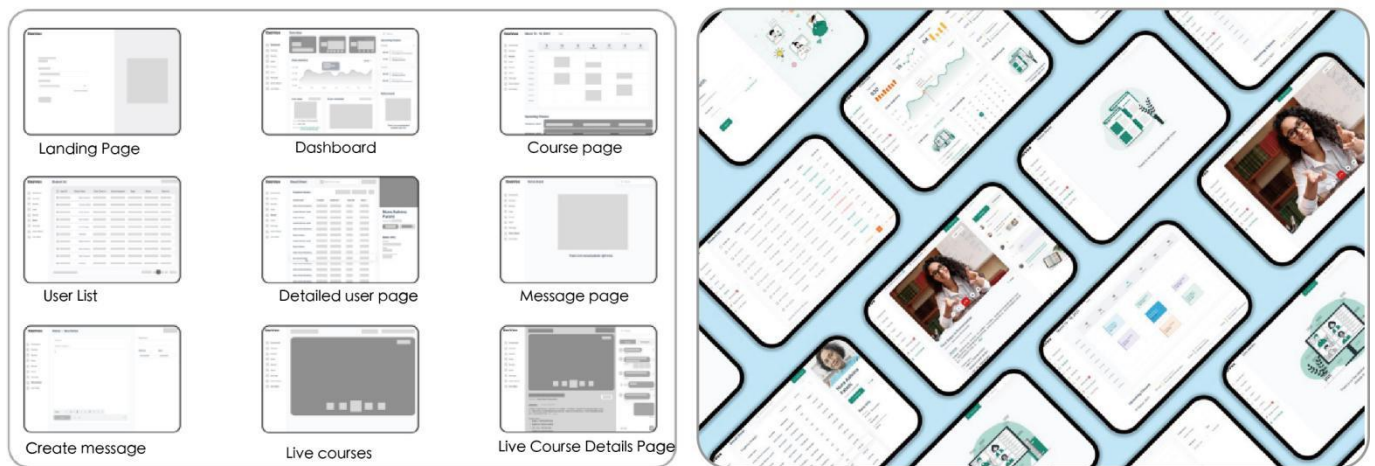
Software Design—Information Management Platform

On the homepage of the information management platform, physicians can view the rehabilitation status, training compliance, and recovery progress of all patients, facilitating follow-up assessments. When abnormal patient data is detected, physicians can promptly inquire about the patient's condition via remote messaging. In the message management interface, the user platform categorizes and prioritizes messages received by physicians. Physicians can conduct real-time live courses to demonstrate vocal techniques, establishing a comprehensive "monitoring-alert-intervention-education" workflow. All data modules support click-through access to individual patient rehabilitation records (as shown in the Figures 8 and 9).



Source: Author created

Figure 8: Functional Framework Diagram



Source: Author created

Figure 9: Low fidelity and high fidelity UI design for APP

Design Evaluation

This study proposes a design practice DEMO for a voice rehabilitation system for laryngectomy patients based on serious games. To evaluate the rationality and effectiveness of the design, a perceptual usability assessment of the product was conducted using an expert questionnaire scale.

Participant recruitment

This study recruited 20 experts and relevant users, with their basic information presented in the table 4 below.

Table 4: Evaluation Personnel Information Statistics

No.	Expert status	Number of people
1	Vocal rehabilitation training expert	5
2	User Experience Design Expert	6
3	Service Design Expert	3
4	Voice rehabilitation users	6

Source: Author created

Evaluation tasks

This study developed an approximately 2-minute simulation video of the voice rehabilitation service platform. From April 17 to April 30, 2025, expert questionnaires were utilized to evaluate the simulated voice rehabilitation training service program (as shown in the table), aiming to validate its acceptance and assess the relative importance of each component.

First, experts and users were shown simulation videos to share experiences with the rehabilitation service platform. Subsequently, expert questionnaires based on a 5-point scale were administered to evaluate the service functions of different service interfaces in the videos (as shown in Table 5). This assessment aimed to better analyze the design content, serving as a reference for subsequent service recommendations and a basis for implementation priorities.

Table 5: Expert Evaluation Questionnaire

Classification of Design Practice	Evaluation dimensions	Score
Hardware design	Q1: Do you think the audio processing and noise reduction features proposed in this study are reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
	Q2: Do you think the medical interface features proposed in this study are reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
	Q3: Do you think the ergonomic and compatibility features proposed in this study are reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
	Q4: Do you think the sound signal monitoring features proposed in this study are reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
Design of game vocal Software	Q5: Do you think the mapping of voice rehabilitation tasks (translating core training actions into graded gamified tasks) proposed in this study is reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
	Q6: Do you think the multimodal interactive feedback proposed in this study is reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
	Q7: Do you think the gamification design proposed in this study is reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
Management APP design	Q8: Do you think the intelligent training guidance system proposed in this study is reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
	Q9: Do you think the knowledge learning and information acquisition features proposed in this study are reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
	Q10: Do you think the proposed communication platform between patients and doctors is reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
	Q11: Do you think the proposed optimized voice rehabilitation plans are reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
	Q12: Do you think the voice rehabilitation data monitoring features proposed in this study are reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>
	Q13: Do you think the multi-end information exchange functionality (connecting patients, caregivers, and doctors) proposed in this study is reasonable and feasible?	<input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>

Source: Author created

Analysis of evaluation results

The table 6 presents the evaluation scores of the study protocol. Based on the overall data, it can be concluded that the voice rehabilitation product platform in this study exhibits high usability.

Table 6: Expert Questionnaire Scores

Classification of Design Practice	Evaluation dimensions	Score
Hardware design	1.Rationality and Feasibility of Audio Processing and Noise Reduction Functionality	4.56
	2.Rationality and Feasibility of Medical Interface Functionality	4.15
	3.Rationality and Feasibility of Ergonomic and Compatibility Features	4.42
	4.Rationality and Feasibility of Sound Signal Monitoring Functionality	4.62
Design of game vocal Software	5.Rationality and Feasibility of Voice Rehabilitation Task Mapping Functionality	4.38
	6.Rationality and Feasibility of Multimodal Interactive Feedback Functionality	4.57
	7.Rationality and Feasibility of Gamification Design Features	4.64
	8.Rationality and Feasibility of Intelligent Training Guidance System Functionality	4.35
	9.Rationality and Feasibility of Knowledge Learning and Information Acquisition Features	4.21
	10.Rationality and Feasibility of Patient-Doctor Communication Platform Functionality	4.48
	11.Rationality and Feasibility of Optimized Voice Rehabilitation Functionality	4.61
	12.Rationality and Feasibility of Voice Rehabilitation Data Monitoring Functionality	4.32

Management APP design	13.Rationality and Feasibility of Multi-End Information Exchange Functionality (Patients + Caregivers + Doctors)	4.23
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Source: Author created

DISCUSSION

Validation of System Functionality Effectiveness

The intelligent rehabilitation system developed in this study received high expert evaluations across three dimensions—hardware design, gaming software, and management app (average score >4.2/5), validating the scientific rigor and feasibility of its core functionalities. In hardware terminal development, the sound signal monitoring function achieved the highest rating of 4.62 (Table 4.21). Compared to conventional single-LED prompting devices, this system significantly enhanced real-time vocal parameter perception in laryngectomy patients through multimodal feedback combining tactile vibration and visual signals (score 4.57). The gamification design of the voice rehabilitation software scored 4.64, demonstrating the effectiveness of its hierarchical interaction framework and gradient task mapping strategy. The multi-terminal data interoperability feature of the management app (score 4.23) established a "patient-caregiver-physician" tripartite linkage, addressing data silos in traditional rehabilitation and aligning with WHO's continuum of care framework.

Limitations

The limitation of this study lies in the small sample size of participants, with the current test covering only 20 experts, which does not adequately reflect the impact of regional and disease stage differences on the evaluation results. In subsequent research, we plan to conduct more precise qualitative and quantitative analyses by organizing multiple workshops and collecting diverse data to further our investigation.

Moreover, due to the constraints of real-world conditions, the service concepts developed and designed in this study cannot be immediately implemented in practice. Consequently, we are unable to further validate and refine their effectiveness in real-world applications. In future research, we will conduct further analysis and evaluation of these service concepts, advancing the practical development, application, and real-world assessment of the serious game-based voice rehabilitation system service design for laryngectomy patients.

RESEARCH SUMMARY

This study addresses the vocal rehabilitation challenges faced by laryngectomy patients by innovatively developing a digital voice rehabilitation system based on serious games. By integrating gamification design, intelligent hardware, and a multi-terminal management platform, the system effectively resolves three major issues in traditional rehabilitation systems: resource imbalance, poor compliance, and delayed assessment. At the core design level, the study identified four major service gaps through semi-structured interviews and developed systematic service strategies using the KJ method. For hardware terminal innovation, a neck-worn sensor was employed to provide real-time biofeedback via LED tricolor prompts and tactile vibrations (expert rating: 4.62), with its ergonomic design (rating: 4.42) accommodating diverse physiological characteristics. The software system established a two-phase gamified training framework: the foundational phase transformed esophageal pressure control into a jumping obstacle game, while the application phase enabled pronunciation striking interactions through AI voice enhancement technology (rating: 4.64). The management platform achieved multi-terminal data interoperability among "patients-caregivers-doctors" (rating: 4.23), establishing a full-cycle service system encompassing intelligent assessment, remote guidance, and risk warning.

Empirical evaluations demonstrate that the system received high expert recognition in the functional dimension (average score: 4.39). The multimodal feedback mechanism significantly improved training perception accuracy (score: 4.57), while the hierarchical task design transformed traditional mechanical training into an immersive gaming experience (score: 4.64). Limitations include a relatively small sample size and lack of long-term follow-up, necessitating further validation of efficacy in cross-regional clinical applications.

This study presents an innovative paradigm for speech rehabilitation in the digital healthcare era. The research outcomes not only provide technical support for improving the quality of life in laryngeal cancer patients in China but also offer a replicable design framework for the digital transformation of chronic disease rehabilitation.

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