FunBreath: A Novel Interactive Nebulizer Mask with Gamification System for Children's Effective and Enjoyable Treatment

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Abstract

Nebulized therapy is essential for treating respiratory illnesses in children, yet it can elicit fear and resistance. To tackle this challenge, we developed FunBreath—a novel interactive nebulizer mask with a gamification system. By integrating both hardware and software components, we revolutionized the therapy experience. Our approach began with in-depth surveys to understand the needs of children and their parents in relation to nebulized therapy. Subsequently, for the software component, we adopted the mechanics-dynamics-aesthetics framework to create engaging interactive games. For the hardware component, we incorporated a pressure sensor to monitor children's breathing behavior, dynamically influencing gameplay. User studies suggest that the FunBreath system could provide a more effective and enjoyable therapy experience, potentially improving treatment adherence by enhancing children's motivation, increasing their participation, and reducing anxiety during treatment. This work enabled us to distill and contextualize pivotal gamification design principles for medical health products, paving the way for future advancements in this domain.

Keywords: Interactive nebulizer mask, Children's Nebulizer treatment, Gamification strategy

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1. Introduction

Respiratory diseases in children, such as asthma and bronchitis, are common health issues. Nebulization therapy is a widely used and effective treatment method that delivers medication directly to the lungs, quickly alleviating symptoms (Pai & Nahata, 2001; Ari & Fink, 2013). However, due to the underdeveloped cognitive abilities of children, adherence to nebulization therapy is often low. Research shows that approximately 49% of children with asthma exhibit non-compliance behaviors during nebulization, such as crying or refusing to wear the mask, which significantly impacts treatment effectiveness (Erzinger et al., 2007). Therefore, improving children's adherence to nebulization therapy has become a critical issue in clinical settings (Chen et al., 2014).

To improve the treatment experience for children, many hospitals have attempted traditional interventions, such as distraction techniques (Kleiber & McCarthy, 2006), inhaler usage training, optimizing the treatment environment, and improving nebulizer design. Doctors use games, soothing methods, videos, or audio to capture children's attention, reduce their anxiety, and help them maintain stable breathing (Bonini, 2017). Additionally, educational interventions and inhaler training for children have been shown to effectively enhance adherence (Basheti et al., 2007; Yanık, 2018). Some hospitals create cartoon-style, colorful treatment environments to reduce children's fear of unfamiliar settings (Chen et al., 2014). In terms of device design, researchers have developed smaller and more engaging nebulization devices to attract children's attention and encourage their active cooperation (Everard, 2004). For example, masks designed in the form of pacifiers enhance the seal and help reduce children's anxiety (Amirav et al., 2012). However, these traditional methods, while improving children's treatment experience to some extent, often require substantial resource investment, such as one-on-one involvement of doctors and modifications to the medical environment.

In recent years, gamified interventions have been widely applied in the healthcare field (Lukas et al., 2021; Cheng, 2020). Therapeutic games are regarded as one of the effective means to improve children's adherence to medical procedures and reduce fear and anxiety (Buyuk & Bolişik, 2015). Researchers have begun integrating gamification elements into children's nebulization therapy to encourage them to achieve treatment goals, making the process more enjoyable and interactive while alleviating fear (Denman et al., 2007). Gamified medical designs leverage extrinsic motivational mechanisms to stimulate children's intrinsic motivation, thereby promoting behavioral change (Ryan & Deci, 2000; Przybylski et al., 2010). For example, (Fedele et al., 2017) developed a nebulization device that interacts with mobile games, allowing children to earn game points or virtual rewards upon completing the prescribed inhalation time, thereby enhancing their motivation to actively cooperate with treatment. Additionally, VR-based biofeedback systems enable users to observe their own breathing within an immersive virtual environment, providing real-time feedback through color changes or graphical indicators to improve breathing awareness and control (Blum et al., 2020; Cortez-Vázquez et al., 2024). Other studies have employed real-time respiratory monitoring and game feedback for breathing training (Shih et al., 2019; van Delden et al., 2020). These gamified designs offer new approaches to improving children's adherence to nebulization therapy by integrating game elements, making the traditionally monotonous treatment process more engaging and interactive. However, most existing game designs do not fully consider the characteristics of the respiratory mask as an input device, and the playability of these games still requires improvement. We believe that natural interaction combining hardware with game content can provide a superior experience, as exemplified by the motion-sensing game "Ring Fit Adventure" for the Nintendo Switch[1], which skillfully integrates a fitness ring with game content to achieve a high degree of interactivity.

The study proposed an innovative interactive nebulizer mask with a gamification system for pediatric nebulizer therapy, named FunBreath (See Fig. 1). Our objective is to utilize the FunBreath to alleviate fear and anxiety, encourage proactive breathing behaviors, and increase the effectiveness and entertainment of children's nebulizer therapy. The system includes two main elements: (1) a nebulizer mask design that incorporates a pressure sensor to detect breathing behavior and (2) a game design that interacts with an iPad via the nebulizer mask. The main research questions (**RQs**) of this study are as follows:

- **RQ1**: How can an interactive nebulizer mask with a gamification system for children be designed?
- **RQ2**: Is our designed FunBreath effective for children's nebulizer therapy?
- **RQ3**: Is our designed FunBreath enjoyable for children's nebulizer therapy?

Through quantitative experiments, we assessed the system's usability, satisfaction, user experience, and its impact on children's nebulizer therapy. Our main contributions are summarized as follows:

- We developed a novel interactive nebulizer mask (called FunBreath) that integrates gamification elements into children's nebulizer therapy, combining both hardware and software components to enhance the therapeutic experience.
- Quantitative experimental results suggest that our FunBreath system improves children's enjoyment and motivation through engaging game narratives, encouraging better adherence, and supporting more effective simulated nebulizer therapy.

[1]https://ringfitadventure.nintendo.com/

Figure 1: Our designed FunBreath with gamification system: This paper presents a therapeutic game where children play the role of the "Big Bad Wolf" blowing down the houses of the Three Little Pigs. Through a cartoonized breathing mask, children undergoing nebulization therapy can interact with the game on the screen, enhancing both the effectiveness and enjoyment of the treatment.

- We successfully applied the Mechanics-Dynamics-Aesthetics (MDA) framework, traditionally used in game design evaluations, to the development of a healthcare-related game. This novel use of the MDA framework demonstrates its effectiveness not only in academic evaluation but also in guiding the design of health intervention systems.

2. Related Works

In this section, we reviewed relevant studies on gamified interventions in the healthcare field, particularly their applications in improving children's adherence to treatment. Additionally, we explored the theoretical foundations of how gamification influences user behavior and discussed game design frameworks.

2.1. Gamification Intervention

"Gamification" or "serious games" refer to the incorporation of game design elements into non-game contexts, aiming to enhance user engagement and motivation (Deterding et al., 2011; Pouls et al., 2022). As an intervention strategy, the core of gamification lies in using specific game elements such as goal setting, challenge levels, reward mechanisms, real-time feedback, and narrative storytelling to drive desired behavioral changes (Deterding et al., 2011; Kapp, 2012). This approach has been widely applied across various domains, including education, sports, and healthcare (Gini et al., 2024; Postma et al., 2023; O'Donnell et al., 2017).

Previous studies have shown that gamified interventions effectively enhance children's engagement and treatment adherence (Hamari et al., 2014; Bonini & Usmani, 2018). For instance, (Chang et al., 2008) explored a "playful toothbrush" system that uses motion tracking and gamified interaction on a mirror to transform toothbrushing into an activity children enjoy, significantly improving their brushing skills and frequency. Additionally, distraction is a common strategy to improve children's treatment experiences by helping them forget about the "frightening" procedures they are undergoing (Kleiber & McCarthy, 2006). However, in some serious games, overly captivating gameplay can distract participants from the core activity. For example, in the virtual reality breastfeeding game designed by (Tang et al., 2023), the gamification's inherent emphasis on goals and achievements may detract from the focus on caring for the baby, thus affecting the seriousness and intimacy of the simulation. In contrast, our game operates differently, as it aims to encourage children to complete core activities through game interactions, making such distractions beneficial.

Gamified interventions for children must also consider their abilities, preferences, and characteristics. Many breathing training games adopt child-friendly themes and metaphors, such as "watering flowers with an elephant" (Gül, 2018) or "blowing out candles." To meet diverse needs, (van Delden et al., 2020) developed a suite of games called "SpiroPlay" to improve the quality and adherence of home-based pulmonary function monitoring in children with asthma through engaging and personalized gamified methods. This adjustable tablet-based game suite (planned to include 11 games, with 3 described in the study) allows children to select content based on their adaptive abilities and interests. The design of game metaphors involved collaboration between children and experts to create elements appealing to children, such as fire-breathing dragons or soccer-playing characters. However, it appears to lack an interactive system, instead relying on visual stimuli to elicit children's behavioral responses, with measurements dependent on doctors observing the child's breathing. In addition to metaphor-based games, recent research has also explored using breathing signals as a direct interaction modality for controlling games. Notably, the BREATHTURES project (Burr et al., 2023) defined distinct breathing patterns for game control, while the AirRes Mask system (Tatzgern et al., 2022) employed precise breath detection through a mask to facilitate interactions in virtual environments.

Reducing children's fear of medical procedures is another major goal of gamified interventions (Denman et al., 2007). Philips developed the miniature scanner "Kitten Scanner"[2], which uses interactive games to help children understand the MRI scanning process, effectively alleviating their fear. In this interactive game, young patients assist an elephant and its friends in undergoing MRI scans, learning the importance of staying still to achieve quality scan images. Our system incorporates a cartoon design for the breathing mask to reduce children's fear of nebulization therapy.

In summary, gamified interventions provide new solutions for improving children's adherence to nebulization therapy by introducing engaging and interactive

[2]https://www.red-dot.org/magazine/philips-kittenscanner

therapeutic games. These interventions help children learn new skills, offer appropriate distractions, meet diverse interests, and reduce the fear associated with medical procedures. However, most current games rely on tablets or smartphones. While some commercial games use microphones as input devices for interaction, such as blowing up balloons or extinguishing fires (Bosboom et al., 2023). In the specific context of nebulization therapy, we aim to utilize existing breathing masks as input devices. Additionally, further research and exploration are needed to enhance the playfulness of games and improve children's gaming experiences.

2.2. Theoretical Foundations of Gamification for Behavioral Change

2.2.1. Psychological Foundation for Gamification

Many studies have explored different theoretical foundations, particularly the psychological explanations for the effects of specific gamification elements or designs. According to a review's statistical findings (Krath et al., 2021), Self-Determination Theory (SDT) (Ryan & Deci, 2000; Ryan, 2017) is the most widely adopted theory in gamification research, appearing nearly ubiquitously. Other theories, such as Flow Theory (Czikszentmihalyi, 1990), Constructivist Learning Theory (Piaget, 1952), Experiential Learning Theory (Kolb, 2014), and Cognitive Load Theory (Sweller, 1988), have also garnered varying degrees of attention.

Self-Determination Theory (SDT) is a prominent psychological theory focusing on human motivation and individual development (Ryan & Deci, 2000; Ryan, 2017). SDT posits that individual behavior is driven by intrinsic and extrinsic motivation. Intrinsic motivation arises from interest in the activity itself, while extrinsic motivation stems from external rewards or pressures. In gamification design, the core objective is to stimulate players' intrinsic motivation to enhance engagement and promote behavioral change (Cheng & Ebrahimi, 2023). SDT identifies three basic psychological needs: autonomy, competence, and relatedness. Fulfillment of autonomy enhances an individual's sense of self-determination, thereby increasing intrinsic motivation; fulfillment of competence enables individuals to feel effective and capable, encouraging them to pursue challenges and skill development; and fulfillment of relatedness involves building connections with others and feeling accepted, which fosters social support and a sense of belonging. Game designers can apply SDT principles to attract and retain players by designing mechanisms that meet their needs for autonomy, competence, and relatedness (Zichermann & Linder, 2010).

Flow Theory is another important framework in gamification design (Czikszentmihalyi, 1990). The flow state describes a highly focused state of total immersion often experienced when the level of challenge matches an individual's skills and is accompanied by a sense of enjoyment (Nakamura et al., 2002). In gamification, flow theory is used to create experiences that continuously engage players and sustain their high level of involvement. Key elements for achieving a flow state include clear goals, immediate feedback, a balance between challenge and skill, deep concentration, a strong sense of control, a temporary loss of self-awareness, and altered perception of time (Nakamura et al., 2002). By maintaining players in a flow state, designers can foster sustained engagement motivation, thereby encouraging positive behavioral changes (Hamari & Koivisto, 2014; Csikszentmihalyi, 2000). Evaluating the flow state allows researchers to understand players' immersion levels, such as focusing on gameplay to the exclusion of ongoing nebulization therapy.

However, the above theories are primarily used to evaluate whether gamification elements achieve their objectives, but they fall short in guiding the specific design of complete games as they do not encompass the entire game design process.

2.2.2. Framework for Gamification Design

Unlike the foundational theories mentioned earlier, some studies aim to propose a set of gamification design frameworks and guidelines. One well-known framework is the "Six Steps to Gamification (6D)" proposed by (Hunter & Werbach, 2012), a systematic method divided into six steps. First, identify objectives, which may include increasing user engagement, enhancing learning outcomes, or promoting behavioral change. Next, conduct user research to understand their needs, motivations, and preferences. Then, select appropriate game elements based on the goals and user analysis, design a user experience prototype, and iteratively optimize it based on testing results. Although this framework outlines the overall approach to game design, it fails to explicitly link the relationships between motivation, needs, and game elements.

Another widely accepted framework is the Mechanics-Dynamics-Aesthetics (MDA) model proposed by (Hunicke et al., 2004). The MDA model bridges the gaps between game design and development, game critique, and technical research by dividing game design into three core elements: mechanics, dynamics, and aesthetics. Mechanics involve the basic rules and building blocks of the game; dynamics describe behavioral patterns arising during player interactions; and aesthetics refer to emotional responses and aesthetic experiences elicited when players interact with the game system. The strength of the MDA model lies in providing designers and users with two distinct perspectives. Designers focus on the technical aspect, aiming to create a series of mechanics and dynamics to encourage interaction and elicit specific aesthetic responses. From the user perspective, the model emphasizes aesthetic responses first, followed by a reverse analysis of dynamics and mechanics. This user-centered approach avoids over-reliance on technical aspects. While this framework has been widely applied in academic game analysis, its industrial application remains relatively limited (Xin, 2022). However, we find it particularly suitable for the game design in this study, possibly because our gamification design goals and interactions are simpler than those of large-scale commercial games. For example, in this study, we aim for children to experience aesthetic reactions such as a sense of achievement, challenge, and immersion. These experiences can be achieved through the dynamic of breathing, which is driven by a series of carefully designed mechanisms. Thus, the MDA model provides a clearer and more coherent approach, making it more advantageous than other gamification design frameworks.

In summary, the relevant dimensions of SDT and Flow Theory can effectively support game evaluation. For instance, the Player Experience of Need Satisfaction (PENS) scale, based on SDT (Rigby & Ryan, 2007), can evaluate players' intrinsic motivation and immersion experiences during gameplay. At the same time, the MDA framework offers specific guidance for the game design in this study.

3. The "FunBreath" System Design and Implementation

This section aims to address **RQ1: How to design an interactive nebulizer mask with a gamification system for children?** We first conducted a questionnaire survey to understand the needs of child patients and their parents during nebulization treatment. Based on these insights, we designed the game and developed a prototype system, including the nebulizer hardware and an interactive iPad game.

3.1. Questionnaire Survey

To investigate children's psychological states and coping strategies during nebulization, a survey was conducted with 20 preschool children (aged 4–6 years) and 6 parents (aged 28–35 years). The sample consisted of an equal number of male and female participants for both children and parents. Participants were recruited from local kindergartens and medical institutions, requiring prior nebulization experience and the ability to complete the questionnaire. Children with severe language or cognitive impairments were excluded. Table. 1 provides specific demographic information, as well as details regarding children's nebulization experience and parental accompaniment.

The questionnaire was designed by the research team and reviewed and optimized by a healthcare professional. The choice of using a questionnaire was informed by the research team's thorough observations of nebulization treatment scenarios and a review of relevant literature, which highlighted the potential for negative emotions during treatment. Our focus was on the causes of these emotions and corresponding coping strategies. The questionnaire consisted of two sections (single-choice and multiple-choice questions): (1) child-friendly questions to capture children's feelings and behaviors during treatment, and (2) questions for parents to provide supplementary data on children's behavior and coping strategies (see questionnaire in Appendix A). Considering that children might be unable to

Table 1: Demographic and Treatment Experience Survey for Preschool Children and Their Parents in Nebulization Therapy.

Category	**Children**	**Parents**
Age Range	4-6 years	28-35 years
Gender Ratio	Boys: 10, Girls: 10	Male: 3, Female: 3
Nebulization Frequency	Once: 5 (25%), More than once: 15 (75%)	NA
Accompanying Situation	NA	Always accompany: 4 (67%), Sometimes accompany: 2 (33%), Never accompany: 0 (0%)

read (Hiniker et al., 2019; Whitehurst & Lonigan, 1998; Clark & Casillas, 2015), researchers explained the options and assisted in completing the questionnaire. Data collection strictly adhered to standardized procedures, and all data were anonymized to protect participants' privacy.

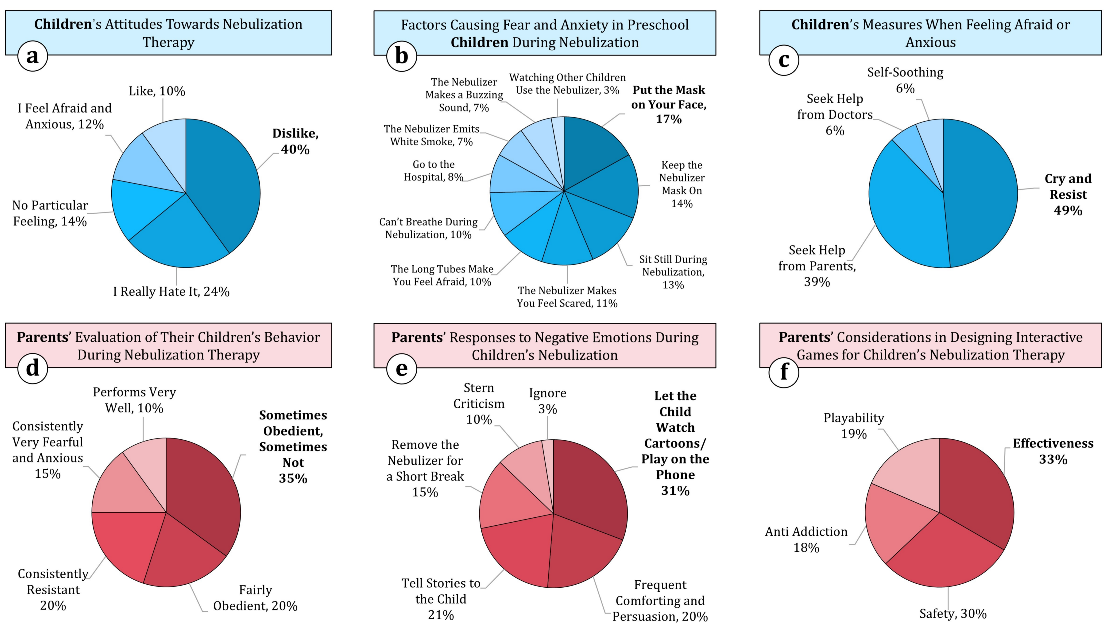

Figure 2: Nebulization therapy-related questionnaire results summary for children (Questions (a), (b), and (c)) and their parents (Questions (d), (e), and (f)).

3.1.1. Children's Responses

Fig. 2 (a) shows that most children have negative attitudes toward nebulization treatment, with only 14% liking the process and 12% expressing strong fear. Fig. 2 (b) identifies key causes of fear, such as discomfort from wearing the nebulizer mask and fatigue or breathlessness from prolonged sessions. These issues may result from the equipment's lack of user-friendliness or children's difficulty maintaining focus during the 10–15 minute treatment. Fig. 2 (c) reveals that frightened children often cry, resist, or seek parental comfort, with fewer attempting self-regulation or seeking help from doctors.

3.1.2. Parents' Perspectives

Parents' feedback closely mirrors children's reactions. Fig. 2 (d) shows that most parents observe negative emotions in their children during nebulization treatment, with only 10% of parents describing their child's performance as "good." Fig. 2 (e) outlines parents' coping strategies, such as using electronic devices or storytelling to distract their children, while few opt for short breaks or strict discipline. Fig. 2 (f) highlights parents' concerns about interactive nebulization games, focusing on effectiveness and safety, with half also emphasizing anti-addiction features and playability, reflecting a balance between entertainment and education.

Overall, children commonly exhibit negative emotions and fear during nebulization treatment, primarily due to discomfort from the nebulizer mask and fatigue from the prolonged process. Their typical response includes crying, resisting, or seeking comfort from parents. Parents observe similar behaviors and primarily use distractions like electronic devices or storytelling to calm children during treatment. Key parental concerns about interactive games focus on effectiveness, safety, anti-addiction features, and playability.

3.2. Game Design Process

In the game software design phase, we first explored suitable metaphors and themes for nebulization treatment. Then, we employed the MDA framework to design the game in detail, and finally, developed a game prototype using tools like Unity.

3.2.1. Concept Design

To design an appropriate game theme, we organized a workshop. It is worth noting that the workshop's goal was limited to creating suitable metaphors and themes for children's nebulization treatment, such as "blowing balloons" or "blowing out candles," rather than designing comprehensive game elements (this is discussed in Section 3.2.2). Drawing on the Co-design method by (van Delden et al., 2020), we collaborated with stakeholders, including a design expert with over ten years of experience in children's game development, two researchers, four graduate students specializing in interdisciplinary design, a pediatric respiratory therapist with clinical experience, and two six-year-old children (the children of one of the graduate students and the design expert). All participants were recruited through internal academic and clinical networks.

First, the research team presented the findings from the preliminary investigation (see Fig. 2) and outlined the workshop's goal: to introduce creative metaphors that make breathing exercises engaging for children, reduce fear of nebulization, and enhance the treatment experience. The entire workshop was audio-recorded, and researchers simultaneously documented observational notes to ensure comprehensive capture of the discussion content. The process included: (1) Group Discussion: Participants discussed their understanding of children's breathing and brainstormed creative metaphors. They proposed ideas and explored breathing-related themes to spark imagination and foster idea generation. (2) Sketch Creation: Participants visualized their metaphors as sketches, encouraging free expression (see Fig. 3 (a)). All sketches and discussion content were independently reviewed by two researchers to ensure accurate interpretation; any discrepancies were resolved through consensus discussions. Ideas were grouped into two directions: using "breathing" as a physical force to drive objects (e.g., "blowing air to push a roller coaster," "spinning a lucky wheel," "an elephant spraying water") and metaphorically representing the process or impact of "breathing" (e.g., "blowing musical notes," "breathing to grow pumpkins," "fish blowing bubbles"). (3) Concept Selection: Participants voted on final game concepts ("The Wind" and "The Three Little Pigs"), with child participants' opinions prioritized. While both concepts are planned for future development, this paper focuses on the realization of "The Three Little Pigs." Below are the concept descriptions (see Fig. 3 (b)):

- The Wind: In this original theme, children play a chick generating gusts of wind by blowing air, aiming to wake all farm animals before a storm arrives.
- The Three Little Pigs: This game is adapted from the classic fairy tale "The Three Little Pigs," which is well-known among children in China. The story depicts three pigs building houses from straw, wood, and bricks, with a big bad wolf attempting to blow them down. This game lets children play the wolf blowing down houses made of straw, wood, and bricks to progress through levels.

It is worth noting that, although the "Big Bad Wolf" character in traditional tales may carry some moral ambiguity, our game design does not aim to portray violent behavior. The primary message of the original story is to explore how factors such as the sturdiness of houses and the pigs' work ethic influence the outcome, rather than emphasizing the negative traits of the "Big Bad Wolf." The core purpose of the game is to simulate the act of "blowing down houses" through breathing actions, with the role-playing of characters solely serving to accompany the performance of these actions, without conveying any aggressive or violent connotations. Furthermore, previous studies have shown that preschool-aged children are capable of clearly distinguishing between the rules of fictional games and those of the real world (Emde, 2018). Thus, using the well-known story of "The Three Little Pigs" as a metaphor is expected not only to evoke familiarity and enjoyment in children but also to significantly minimize the risk of negative moral influence.

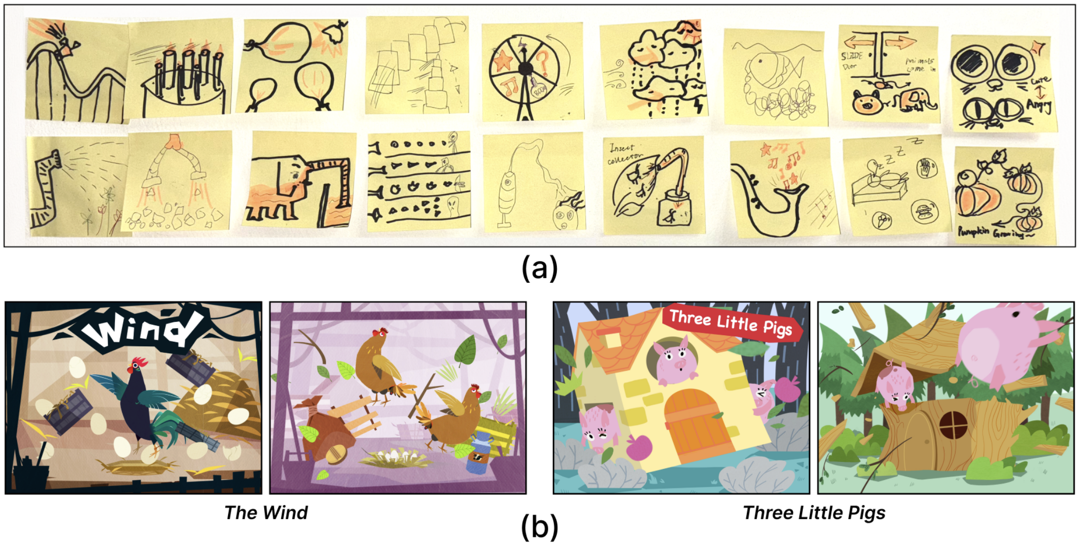

Figure 3: Final Drawing Proposals from the Workshop. (a) The drawings show the metaphor themes proposed by participants in an adapted format as the selected results. (b) The two final metaphors selected are The Wind and Three Little Pigs, represented as concept drawings.

3.2.2. Game Prototype Design

In this study, we adopted the MDA (Mechanics-Dynamics-Aesthetics) framework (Hunicke et al., 2004) to construct a systematic gaming experience. The "Aesthetics" component emphasizes the player's experience and emotions, including sensory enjoyment, narrative immersion, and challenge. "Dynamics" are the interactive mechanisms shaping these experiences, emerging from "Mechanics"—the fundamental rules and operations defining player actions. Designers use mechanics to create dynamics, leading to aesthetic experiences. From the user's perspective, the process begins with eliciting aesthetic experiences, followed by designing dynamics to evoke them, and finally exploring how these dynamics are implemented through mechanics. Thus, this user-centered design follows an Aesthetics-Dynamics-Mechanics order. Table. 2 and Fig. 3 present our design approach, and the following sections elaborate on each component.

- **Aesthetics:** We enriched the game's narrative and fantasy by integrating children's exhalation with the story of "The Three Little Pigs," specifically the "big bad wolf blowing down the pigs' houses." This design encourages correct and rhythmic breathing exercises. By alternating gameplay with animated clips, children experience the challenge of blowing as the wolf within a familiar story, enhancing sensory and emotional engagement. The straw, wood, and brick houses provide layered challenges, seamlessly combining fantasy with practical breathing exercises (see Fig. 4 (A)).

Table 2: Game design of our FunBreath using the Mechanics-Dynamics-Aesthetics (MDA) framework (Hunicke et al., 2004) as a guiding principle.

Aesthetics	**Dynamics**	**Mechanics**
Narrative	Breathing and viewing	The story of the Three Little Pigs
Challenge	Breathing of different depths	Progressively difficult levels
Discovery	Exploring levels	Straw house, wooden house, brick house
Fantasy	Role-playing	Playing as the big bad wolf, completing tasks through breathing
Sensation	Breathing and viewing	From blowing on surrounding flowers, trees, and grass, to blowing off the roof, and finally toppling the entire house
Submission	Repetitive breathing interactions	Gradually advancing levels
Emotion	Breathing	Diverse interactive feedback, time management, and reward mechanisms

- **Dynamics:** The game integrates guided breathing exercises, including controlled deep inhalation and breath-holding, to enhance lung medication deposition and improve treatment outcomes. The strategy alternates regular and deep breathing, with one deep breath after every five regular breaths. Regular breathing generates smaller gusts of wind, while deep breathing produces stronger gusts, creating more impactful in-game effects and increasing interactivity and challenge. Role-playing as the big bad wolf and the integration of animated clips with gameplay further enrich the experience, making treatment more engaging and enjoyable for children (see Fig. 4 (D)).

- **Mechanics:** The game features three levels corresponding to the straw, wood, and brick houses. It begins with an animated clip introducing "The Three Little Pigs," immersing children in the role of the big bad wolf and clarifying objectives. In each level, children use controlled breathing to simulate the wolf's blowing, with regular breaths creating smaller gusts and deep breaths generating stronger gusts to dismantle the houses. Each completed stage triggers animations of the houses collapsing and character reactions, providing visual feedback on progress and preparing children for the next challenge. Integrating breathing actions with interactive scenes enhances the narrative and immersive experience, encouraging natural participation in breathing exercises. The game includes diverse feedback, time management, and reward systems, where different breathing modes yield distinct effects. This not only scientifically guides breathing behavior but also alleviates boredom and anxiety, keeping children actively engaged (see Fig. 4 (M)).

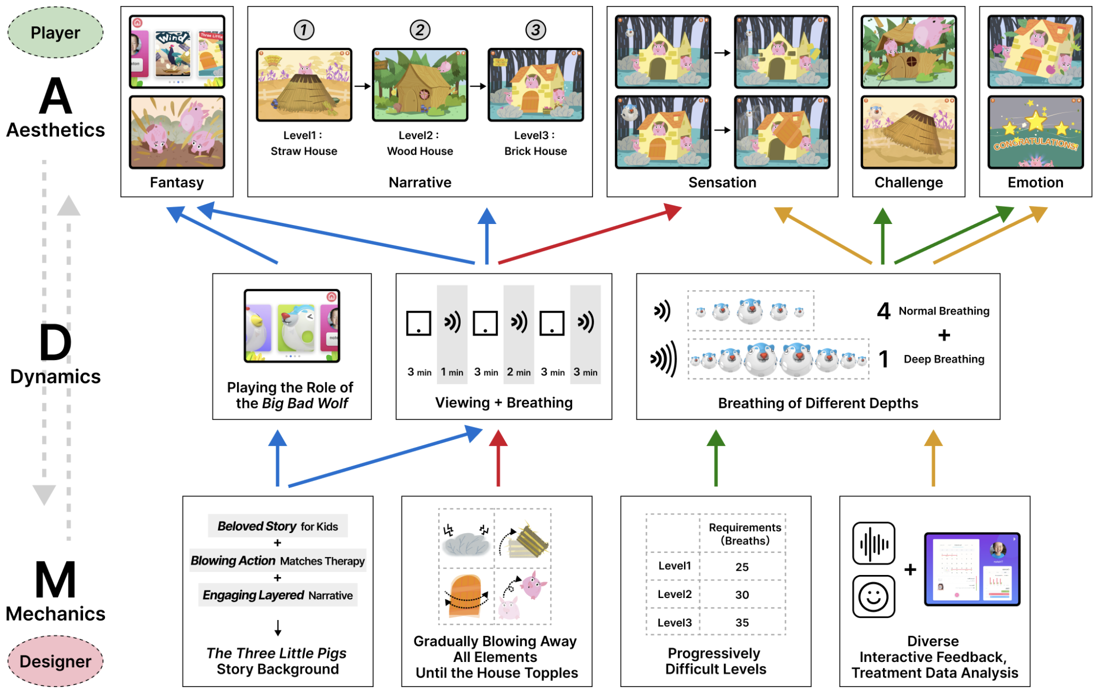

Figure 4: Game design of our FunBreath using the MDA framework (Hunicke et al., 2004) as a guiding principle. Note that the different-colored arrows represent the game mechanics we have designed to elicit the dynamic behaviors of players and ultimately lead to the acquisition of different Aesthetics. Specifically, the designer implemented four core game mechanics: The Three Little Pigs Story Background, Gradually Blowing Away All Elements Until the House Topples, Progressively Difficult Levels, and Diverse Interactive Feedback and Treatment Data Analysis. These mechanics correspond to three key dynamics: Playing the Role of the Big Bad Wolf, Viewing + Breathing, and Breathing of Different Depths. Through these dynamics, players experience various aesthetic elements, including Fantasy, Narrative, Sensation, Challenge, and Emotion.

3.2.3. Software Implementation

The FunBreath game was developed using the Unity platform with C# as the primary programming language. Game art assets were created in Photoshop 2023 and integrated into Unity to optimize logic design, interaction, and visual performance.

- **Game Flow:** Upon launching the FunBreath app, users access the main interface and start the game after connecting the hardware. First-time users are guided through a tutorial, while returning users can enter gameplay directly. The game features a progressive level design where players complete three stages in sequence before viewing treatment results for feedback (see Fig. 5 (a)). A functional menu allows pausing, exiting, and adjusting progress at

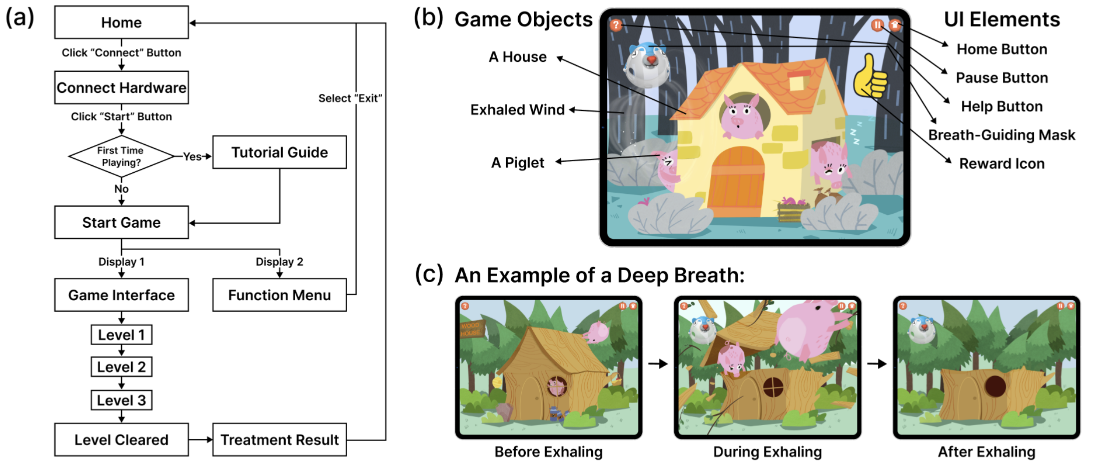

Figure 5: Software Implementation. (a) Displays the flowchart of the FunBreath system. (b) Highlights key game objects and UI components, using the brick house level as an example. (c) Shows the three stages of a deep breath—before, during, and after exhaling, using the wooden house level as an example.

any time.

- **User Interface Overview:** The game's user interface consists of game objects and UI elements (see Fig. 5 (b)). Among the game objects, houses and pigs form the narrative and functional core, guiding player tasks. The wind generated by the player's breath serves as the main interaction medium, dynamically affecting core elements and other scene objects to enhance immersion. UI elements, such as help, home, and pause buttons, along with a wolf mask for guiding breathing rhythm and reward icons for feedback, provide functional support and real-time responses.

- **Game Dynamic Performance:** FunBreath employs a dynamic mapping mechanism to convert breathing data into real-time scene responses (see Fig. 5 (c)). Object movements, such as displacement, rotation, and path-based motion (e.g., doors swinging, debris scattering), are achieved through keyframe animations for smooth effects. Scene changes, like house breakage and mud splatter, use segmented animations, while particle effects simulate wind and dust to enhance visuals and immersion.

3.3. Nebulizer Mask Design

3.3.1. Appearance Design

The nebulizer mask, designed as a big bad wolf to match the game theme (see Fig. 6), uses familiar imagery to reduce fear and resistance (Zhang, 2021).

Rounded, ergonomic lines ensure comfort and safety, while breathable, hypoallergenic medical-grade silicone allows prolonged wear. Its optimized size provides a snug fit for effective treatment. Soft colors and vivid patterns further enhance its child-friendly appeal (Coad & Coad, 2008). The main body of the mask measures approximately 9.3 cm (length) × 6.3 cm (width) × 8.5 cm (height).

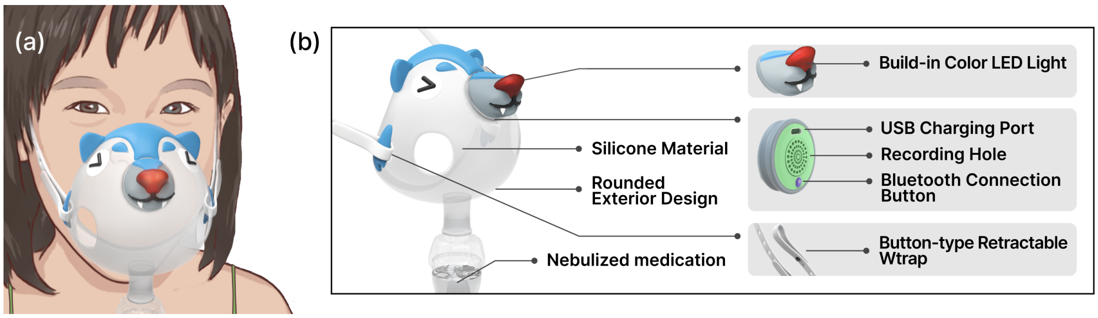

Figure 6: Appearance Design of our interactive nebulizer mask. (a) Front view of the rendered mask.(b) Side view of the Nebulizer mask, showcasing the structure and functions of each component.

3.3.2. Functional Design

The nebulizer's "smart hardware" system uses the XGZP6847A silicon pressure sensor, known for precision and stability. A model with a pressure range of -1 to 1 KPa monitors real-time breathing data via a hose connected to the mask. Data is transmitted by an Arduino UNO and HC-05 Bluetooth module to Unity software every 200 milliseconds, synchronizing with game content. Higher breathing intensity produces stronger in-game effects. A sound sensor controls an LED light, making the wolf's nose glow brighter with louder sounds (see Fig. 7).

4. Evaluation and Method

To address **RQ2: Is our designed FunBreath effective for children's nebulizer therapy?** and **RQ3: Is our designed FunBreath enjoyable for children's nebulizer therapy?** We conducted a quantitative experiment aimed at evaluating the differences between this system and existing intervention methods (e.g., regular casual games), particularly in terms of their impact on breathing behavior and treatment effectiveness.

Our hypotheses (H) were as follows:

- **H1:** Compared to standard games, the FunBreath will significantly improve children's breathing behavior, thereby enhancing the effectiveness of nebulizer therapy.

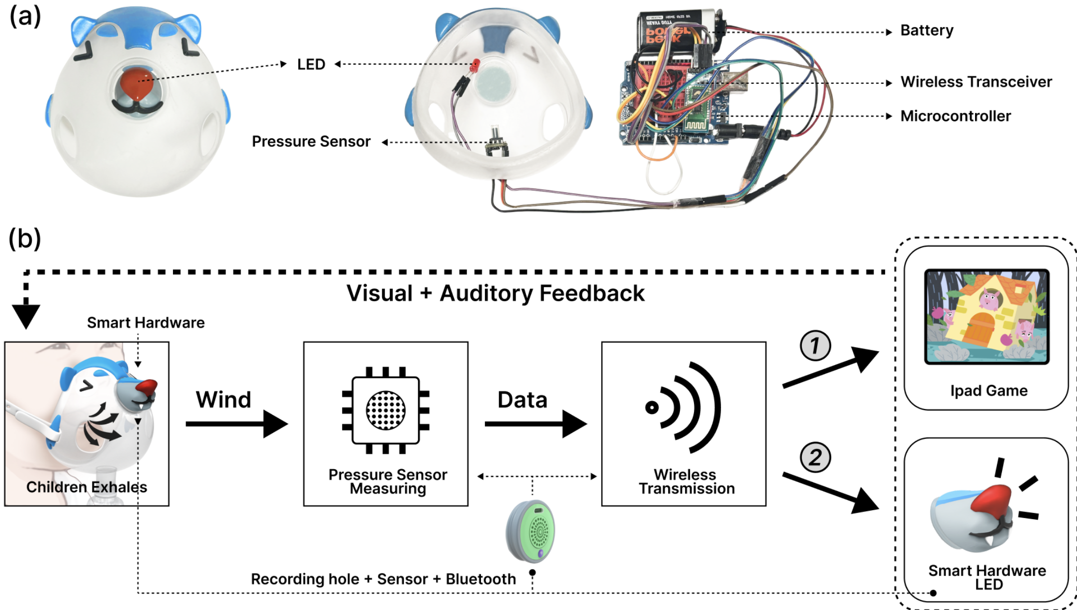

Figure 7: Function design of our interactive nebulizer mask. (a) Prototype device for the Nebulizer mask: Illustrates the hardware components, including the XGZP6847A silicon pressure sensor, Arduino UNO board, HC-05 Bluetooth module, and the mask. (b) Data application workflow: Demonstrates the data processing and application scenarios, highlighting two data pathways: transmission to an iPad for game feedback and controlling LED brightness for real-time visual feedback.

- **H2:** Compared to standard games, the FunBreath will more effectively induce a flow state in patients, reducing anxiety and increasing focus on the game, thereby distracting from the discomfort of the therapy.
- **H3:** Compared to standard games, the FunBreath will have higher usability and playability, stimulating greater engagement and interaction from children.
- **H4:** Compared to standard games, the FunBreath will receive better user evaluations in terms of overall game experience.

4.1. Participants

This study recruited 30 child participants aged 4 to 6, with an equal gender distribution (15 boys and 15 girls). All participants had prior experience with nebulization treatment; exclusion criteria included children with severe language or cognitive impairments. Recruitment was conducted through local educational institutions, with information disseminated via internal notifications. Parents or guardians voluntarily registered their children for participation. Informed consent forms were signed by the participants' guardians (parents), who were fully informed about the study and agreed to their children's participation. In addition to obtaining parental consent, the researchers also explained the experimental procedures to the children in an age-appropriate manner and obtained their verbal assent in the presence of the parents, ensuring agreement from all parties involved. Throughout the experiment, all children were accompanied by their guardians and were free to withdraw at any time. At the conclusion of the experiment, the children received small gifts as a token of appreciation. This study was reviewed and approved by the institutional ethics committee.

4.2. Experiment Design

This study employed a single-factor repeated-measures experimental design. Each participant experienced two different interventions in random order, completing the experiments over two separate sessions within one week. It is important to note that no actual medication was used during the experiments; participants were informed that they were simulating "nebulization treatment." Participants performed rhythmic deep breathing and other actions as required by nebulization treatment, with guidance provided by the researchers throughout the process. Each game session lasted 5 minutes. After completing each intervention, researchers assisted participants in completing a questionnaire and conducted a brief interview to capture their subjective experiences. It is particularly worth noting that young children, due to their age, limited literacy, or difficulty articulating their thoughts, may face challenges in providing feedback (Hiniker et al., 2019; Whitehurst & Lonigan, 1998; Clark & Casillas, 2015). To address this, researchers assisted participants in understanding the questionnaire and completing their responses. This approach aligns with research methodologies that emphasize collaboration and cooperation between researchers and participants (Druin, 1999). In practice, as playing games is very familiar to children in this age group, participants were able to understand the questions and provide appropriate answers after a simple explanation.

Specific intervention conditions were as follows:

- **Control Group:** During the simulated nebulized therapy, participants experienced a regular casual game suitable for children aged 4 to 6, such as Tetris. (Based on preliminary research, children undergoing nebulization therapy can distract themselves through games or videos. Therefore, we have chosen "Tetris" as the control group game, as it is relatively simple and suitable for children aged 4 to 6. To minimize the impact of individual game preferences on the experimental results, all participants will experience the same "Tetris" game during the simulated treatment.)

- **Treatment Group:** During the simulated "nebulized therapy", participants used our developed FunBreath system and experienced an interactive game based on the story of "The Three Little Pigs."

4.3. Measurement

We comprehensively evaluated the impact of FunBreath on children's nebulization treatment process using four indicators (requiring approximately 5 minutes to complete) and interviews:

1. **Breathing Behavior:** Utilizing a pressure sensor, we recorded participants' respiratory rate and volume during the experiment to evaluate the potential impact of the game on breathing behavior. We established a pressure threshold where three consecutive pressure readings surpassing this threshold are considered valid exhalations. By summing the readings exceeding the threshold, we calculated the average pressure value of all exhalations and the exhalation frequency to quantify the effects of the system on the participants' breathing behavior.
2. **Game Motivation and Need Satisfaction:** We employed the Player Experience of Need Satisfaction (PENS) scale, based on Self-Determination Theory (SDT) (Rigby & Ryan, 2007), to measure players' intrinsic motivation and experiences during gameplay. By assessing these dimensions, designers can better understand players' needs and optimize the gaming experience. The PENS model comprises five dimensions, but "Relatedness," which examines players' sense of connection and belonging to others (e.g., other players, game characters, or the community), is irrelevant to the game discussed in this study. Therefore, we selected four relevant dimensions: Autonomy, Competence, Immersion, and Intuitive Controls. Among these, we identified 18 items pertinent to this study, such as: "My ability to play the game matches the game's challenges." Participants rated each item on a 7-point Likert scale, with higher scores indicating greater satisfaction with the corresponding need.
3. **Game User Experience Satisfaction:** We used the Game User Experience Satisfaction Scale (GUESS) (Phan et al., 2016) to evaluate participants' overall satisfaction with the game. GUESS includes seven dimensions. Considering that real nebulization environments require maintaining silence and that children are unsuitable for wearing headphones, the Audio Aesthetics dimension was excluded. Finally, we selected six relevant dimensions: Creative Freedom, Enjoyment, Narratives, Personal Gratification, Play Engrossment, and Playability. Within these dimensions, we identified 22 items relevant to this study, such as: "I enjoyed the process of playing this game." Participants rated these items on a 7-point Likert scale, with higher scores indicating greater satisfaction with the corresponding experience dimension.

4. **System Satisfaction:** System satisfaction was measured using the System Usability Scale (SUS) (Brooke, 1996), focusing on items 1, 6, and 9. This scale employs a 5-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), with higher scores reflecting greater satisfaction levels.
5. **Semi-Structured Interviews:** After the experiment, we conducted semi-structured interviews to explore the specific reasons underlying the quantitative results. For example, we investigated key factors related to flow, including: clear goals, immediate feedback, balance between challenge and skill, focus, sense of control, changes in self-awareness, and altered time perception. Through these interviews, we aimed to gain a deeper understanding of participants' perceptions and reactions during the gaming experience.

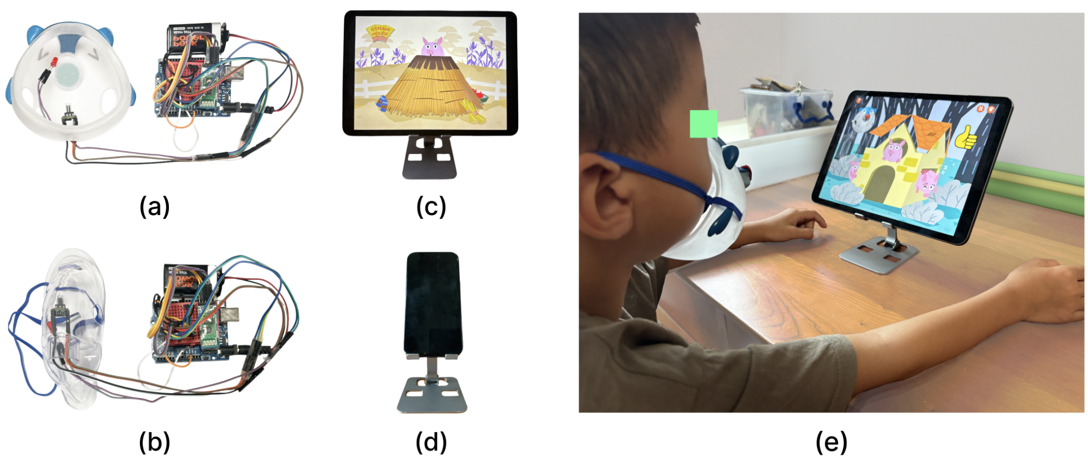

Figure 8: Experimental materials and environment. (a) FunBreath system-specific nebulizer mask equipped with a breathing frequency collection device. (b) Standard disposable children's nebulizer mask equipped with a breathing frequency collection device. (c) An iPad loaded with the experimental game, used for presenting game content and interaction. (d) Audio recording device for capturing participants' qualitative feedback during the semi-structured interview. (e) Experiment environment.

4.4. Material and Procedure

4.4.1. Material

The primary materials and equipment used in this experiment include:

1. **Nebulizer Masks:** A specialized FunBreath nebulizer masks (see Fig. 8 (a)) and Standard disposable children's nebulizer masks (see Fig. 8 (b)). Both types of masks are equipped with a respiratory frequency collection device for real-time monitoring of participants' breathing data.

2. **Experimental Equipment:** An iPad loaded with the experimental games, used to present game content and facilitate interaction (see Fig. 8 (c)).
3. **Questionnaire Tool:** Electronic questionnaires created using the Questionnaire Star platform [3], used to collect participants' subjective experiences and feedback during the experiment.
4. **Recording Equipment:** Audio recording devices used to capture participants' qualitative feedback during semi-structured interviews (see Fig. 8 (d)).

All equipment was calibrated and tested rigorously before the experiment to ensure data accuracy and safety during the experimental process. The research team supervised the entire experiment to ensure that participants completed it in a safe and comfortable environment without experiencing any physiological or psychological discomfort (see Fig. 8 (e)).

4.4.2. Procedure

The experimental procedure is as follows:

1. **Preparation:** Before starting the experiment, researchers provided detailed explanations of the experiment's purpose, procedure, and potential risks to participants and their guardians, and obtained written informed consent. The researchers then fitted the participants with the masks and started the game devices.
2. **Execution:** Participants experienced game content under two different intervention conditions. Each game session lasted 5 minutes, with researchers supervising and recording relevant data throughout.
3. **Questionnaire and Interview:** After the experiment, participants completed questionnaires and participated in semi-structured interviews. Due to the young age of the participants, researchers assisted them in understanding and completing the questionnaires. The interviews focused on participants' subjective experiences and feedback on the game, aiming to supplement the quantitative data.
4. **Completion:** After the experiment, researchers thanked participants and their guardians and provided small gifts to the participants as a token of encouragement.

5. Results

To rigorously compare the performance of two groups across three questionnaires utilizing different point scales, we standardized the participants' scores on

[3]https://www.wjx.cn/

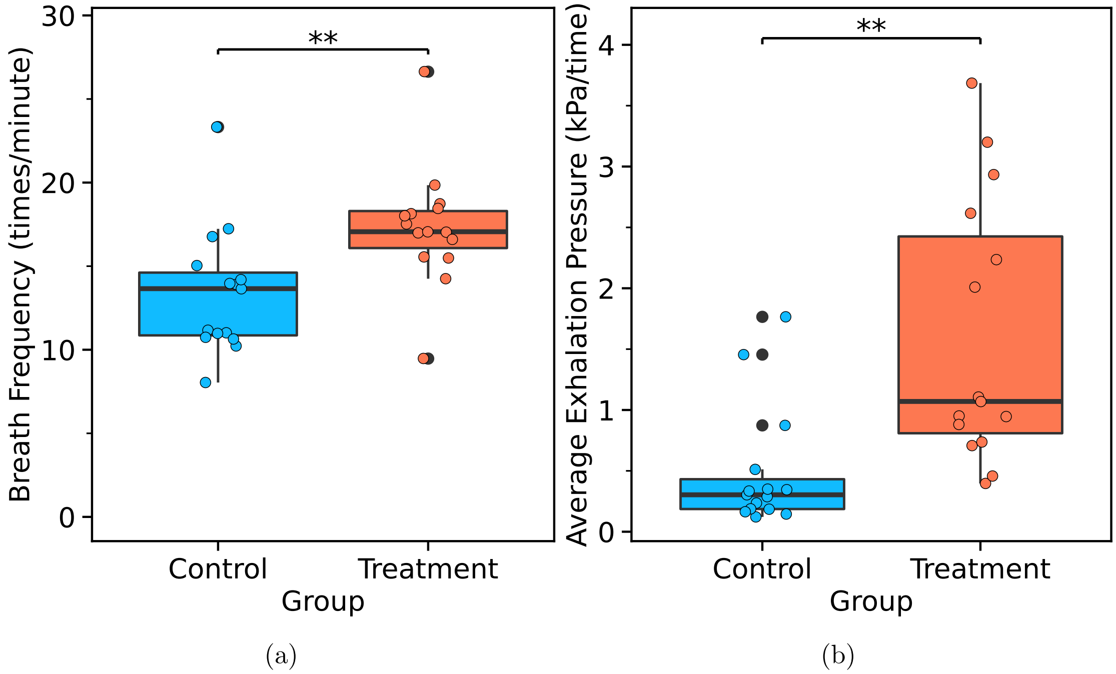

Figure 9: Breathing behavior comparison of two groups. (a) Exhalation pressure. (b) Breath frequency. $* = \text{p} \leq 0.05$; $** = \text{p} \leq 0.01$. Note that the participants in the treatment group had significantly higher median exhalation pressures and breath frequencies compared to those in the control group.

these questionnaires to a uniform scale ranging from 1 to 100. Subsequently, we employed the Shapiro-Wilk test (Shapiro & Wilk, 1965) to ascertain the normality of the human evaluation data distribution. In instances where the data did not exhibit a normal distribution, the Wilcoxon signed-rank test (Wilcoxon, 1992; Vargha & Delaney, 2000) was employed to evaluate the differences in breathing behavior and user experiences between the treatment and control groups. For statistical analysis, we utilized the Pingouin Python package (Vallat, 2018) to conduct hypothesis testing. Furthermore, the visualization of results in Python was facilitated by leveraging the plotnine package.

5.1. Breathing Behavior

Given that the data for average exhalation pressure per participant did not follow a normal distribution, a Wilcoxon signed-rank test was conducted to compare the median scores between the control group (Mdn = 0.303 kPa/time; median) and the treatment group (Mdn = 1.070 kPa/time) (see Fig. 9 (a)). The test revealed a statistically significant difference between the two groups, $W = 15.0$, $p = 0.008 \leq 0.01$. The analysis also yielded a rank-biserial correlation (RBC) of -0.75, indicating a moderate negative effect size, and a Common Language Effect Size

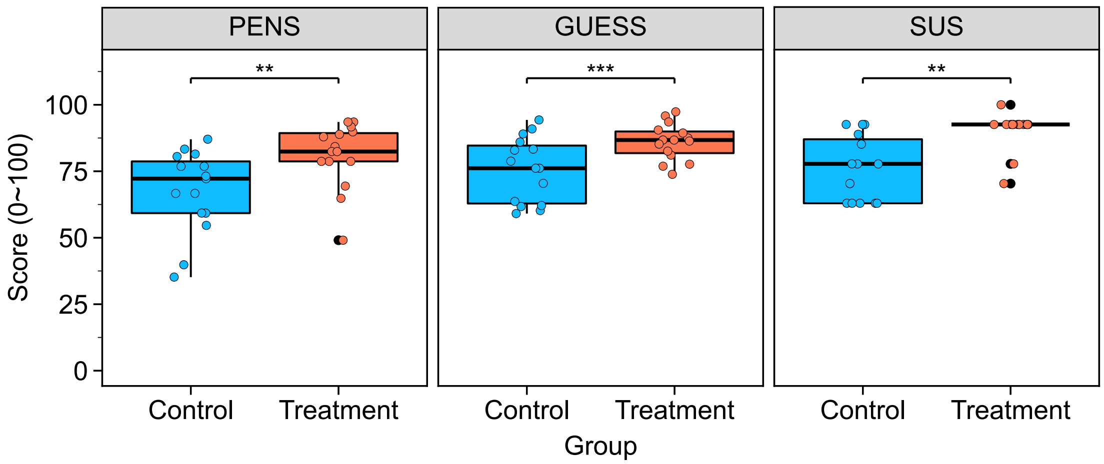

Figure 10: Overall user experience evaluation and comparisons of two groups using three widely used questionnaires. To clearly compare the performance of two groups across three questionnaires with different point scales, we standardized the participants' scores on the three questionnaires to a scale of 1-100. $*$ =p $\leq$ 0.05; $**$ =p $\leq$ 0.01, $***$ =p $\leq$ 0.001. Note that the participants in the treatment group exhibited significantly higher median scores compared to those in the control group for user experience.

(CLES) of 0.107. These results indicate that participants in the treatment group exhibited significantly higher median exhalation pressures compared to those in the control group.

Similarly, for breath frequency per participant, which also did not follow a normal distribution, a Wilcoxon signed-rank test was performed to compare the median scores between the control group (Mdn = 13.654 times/minute) and the treatment group (Mdn = 17.061 times/minute) (see Fig. 9 (b)). The test identified a statistically significant difference between the two groups, W = 13.0, p = 0.005 $\leq$ 0.01. The analysis produced a RBC of -0.783, suggesting a strong negative effect size, and a CLES of 0.173. These findings suggest that participants in the treatment group had significantly higher median breath frequencies compared to those in the control group.

These findings demonstrate that the FunBreath intervention significantly improves both exhalation pressure and breath frequency. Previous studies have indicated that higher exhalation pressure facilitates deeper deposition of aerosolized medication in the lungs, while a regular and moderately increased breathing frequency is closely associated with improved drug absorption efficiency during pediatric inhalation therapy (Davis et al., 2023). Therefore, we suggest that these behavioral improvements may indicate the potential of the FunBreath system to enhance respiratory efficiency during actual nebulization treatment.

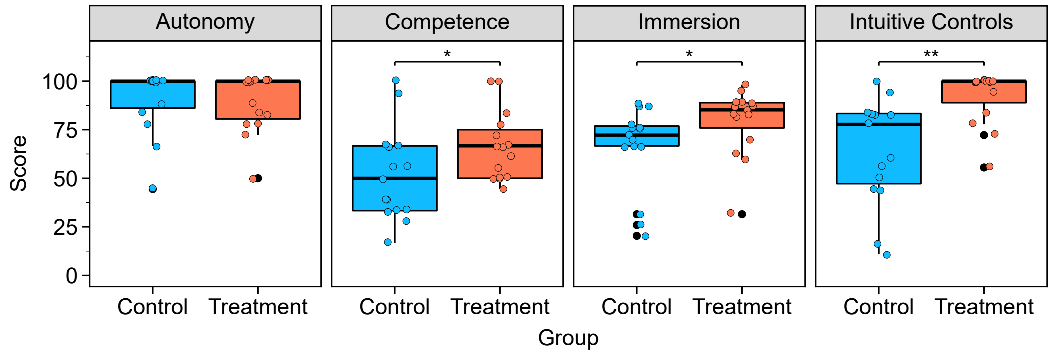

Figure 11: Evaluation and comparisons of PENS across two groups in four dimensions. $* =$p ≤ 0.05; $** =$p ≤ 0.01.

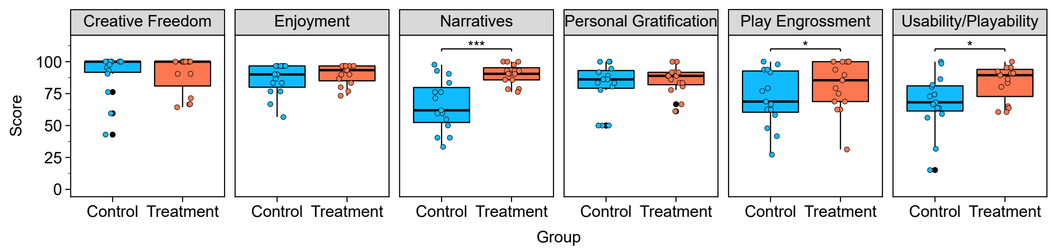

Figure 12: Evaluation and comparisons of GUESS across two groups in seven dimensions. $* =$p ≤ 0.05; $** =$p ≤ 0.01; $*** =$p ≤ 0.001.

5.2. Game Motivation and Need Satisfaction

Given that the data for the overall PENS questionnaire scores per participant did not follow a normal distribution, a Wilcoxon signed-rank test was conducted to compare the median scores between the control group (Mdn = 72.222) and the treatment group (Mdn = 82.407) (see Fig. 10). The test revealed a statistically significant difference between the two groups, W = 12.5, p = 0.005 $\leq$ 0.01. The analysis also produced a rank-biserial correlation (RBC) of 0.792, indicating a strong positive effect size, and a Common Language Effect Size (CLES) of 0.787. These results suggest that participants in the treatment group exhibited significantly higher median PENS questionnaire scores compared to those in the control group.

In terms of the four dimensions of the PENS questionnaire (see Fig. 11), the results indicated that participants in the treatment group exhibited significantly higher median scores in three dimensions: competence, immersion, and intuitive controls, compared to the control group.

5.3. Game User Experience Satisfaction

Given that the data for the overall GUESS questionnaire scores per participant did not follow a normal distribution, a Wilcoxon signed-rank test was conducted to compare the median scores between the control group (Mdn = 76.136) and the treatment group (Mdn = 86.742) (see Fig. 10). The test revealed a statistically significant difference between the two groups, W = 6.0, $p = 0.001 \leq 0.001$. The analysis also yielded a RBC of 0.900, indicating a strong positive effect size, and a CLES of 0.751. These findings suggest that participants in the treatment group exhibited significantly higher median GUESS questionnaire scores compared to those in the control group.

Regarding the seven dimensions of the GUESS questionnaire (see Fig. 12), the results showed that participants in the treatment group exhibited significantly higher median scores in two dimensions: play engrossment and usability/playability, compared to the control group.

5.4. System Satisfaction

Given that the system satisfaction scores per participant did not follow a normal distribution, a Wilcoxon signed-rank test was conducted to compare the median scores between the control group (Mdn = 77.778) and the treatment group (Mdn = 92.593) (see Fig. 10). The test revealed a statistically significant difference between the two groups, W = 0.0, $p = 0.002 \leq 0.01$. The analysis also produced a RBC of 1.0, indicating a very strong positive effect size, and a CLES of 0.851. These findings suggest that participants in the treatment group reported significantly higher system satisfaction compared to those in the control group.

5.5. Interview Results

After the experiment, all participants underwent a 10-minute semi-structured interview. As previously mentioned, considering the young age of the participants, the researchers patiently explained the interview content to support their understanding. The interviews covered participants' preferences for the game, their evaluation of the overall system and game, opinions and suggestions regarding game content, and general feedback on the design (questions provided in Appendix B). All interviews were recorded and transcribed into text. For data analysis, the research team employed thematic analysis (Terry et al., 2017), using an iterative deductive coding process to analyze the 30 interview transcripts. The research team initially selected six representative and diverse interview samples as the preliminary dataset to construct an initial coding framework. These samples were jointly agreed upon by the researcher. Subsequently, the framework was independently applied to the remaining 24 interviews, with continuous modifications and expansions made during the coding process to minimize early-stage bias and enhance the comprehensiveness and saturation of the identified themes. Ultimately, five core themes were derived.

5.5.1. Intrinsic Motivation and Behavioral Changes

Interviews revealed that our game altered children's intrinsic motivation, possibly through several mechanisms. First, the game appeared to enhance their sense of autonomy. Although quantitative data did not show significant differences in this dimension, interviews highlighted that the reward system and dynamic design made children feel more in control during breathing activities, especially deep breathing. For example, P08 noted: *"Every time I blow something away and get a reward, it makes me happy and want to keep playing."* Second, the game boosted children's sense of competence. P03 mentioned: *"When I blow harder, I can create a stronger wind, which makes me feel powerful."* Finally, the intuitive interaction design of FunBreath provided a straightforward and accessible experience, allowing children to naturally engage with the game. P08 remarked: *"I saw the little wolf mask at the top left inhaling and exhaling, and I wanted to follow along."*

5.5.2. Immersion and Flow State

FunBreath may influence users' sense of immersion in several ways, enabling them to enter a flow state. Beyond autonomy and control, the dynamic design of the game, with continuous interaction and immediate visual feedback, successfully redirected children's attention, making them focus more on the game than on the treatment process. Many participants concentrated on game objectives rather than the treatment itself. P05 commented: *"I liked blowing the pigs away and blowing the house down; it was funny and made me forget I was doing nebulization."* This immersion helped them temporarily forget the stress of the treatment process. Additionally, the balance between challenge and skill added to the enjoyment, enhancing their engagement. P03 added: *"I felt like my breath could blow the pigs away, so I wanted to blow harder to send them further."* Finally, the narrative design contributed to the immersion by providing a strong sense of role-play. Children displayed intense focus on completing the game objectives while embodying their roles. P04 shared: *"I felt like I really became the big bad wolf, and I just wanted to blow all the pigs away and complete the game."*

5.5.3. Game Playability Enhanced by Dynamic Design

The variety of dynamic designs significantly enhanced the game's playability. For instance, the intuitive interaction design, mentioned earlier, made it easy for children to engage. Moreover, combining deep and shallow breathing with different task challenges and feedback increased the enjoyment of actions while clarifying objectives and reinforcing a sense of control. P03 stated: *"When I needed to blow harder, I felt more powerful, which made the game more fun to play."* In addition, this dynamic design complemented the role-play aspect of the big bad wolf, significantly enhancing the players' contextual immersion and helping children focus. P01 explained: *"I felt like the little wolf was breathing with me, and the wind came out of the wolf's mouth to blow the house down."*

5.5.4. Mechanics and Narrative Integration

Interviews showed that the FunBreath adaptation of the "Three Little Pigs" story was well-loved by most children, who demonstrated a strong understanding of the story content. P03 remarked: *"I love this game, and I really like 'The Three Little Pigs.' It's much more fun than just watching cartoons during nebulization!"* This appeal stemmed from the game's seamless integration of story narrative and mechanics. The progressive level design aligned closely with the story's plot, allowing children to sequentially challenge the straw house, wood house, and brick house, experiencing a sense of accomplishment as they advanced through tasks and the story. This not only added to the game's enjoyment but also helped children feel connected to the narrative as they completed tasks. Moreover, the integration of breathing interactions with the narrative further enhanced engagement. Each action directly advanced the story, as P03 noted: *"I felt like every time I blew, I was helping the big bad wolf complete the task."* This interactive experience not only increased emotional immersion but also improved children's focus, drawing them deeper into the game.

5.5.5. Aesthetic Evocation and Enjoyment

Although differing slightly from the quantitative results, interviews revealed that nearly all participants expressed strong aesthetic enjoyment, including feelings of joy and satisfaction brought about by the game. The exploratory design and fantasy elements stimulated children's curiosity and imagination. P09 commented: *"I could blow down the pigs' houses in the game, and it felt magical."* On a sensory level, dynamic interactions and destructive feedback increased the fun of the gameplay. P06 shared: *"I saw the chimney spinning like a hula hoop as it flew away—it was so funny."* These vivid visual effects significantly boosted the game's appeal.

6. Discussion

This study examined the impact of a gamified design integrating software and hardware on children's behavior and user experience during nebulization therapy. The key findings of this study indicate that FunBreath significantly improved children's treatment experience by enhancing motivation and participation, and increasing enjoyment and motivation during treatment, thus demonstrating the potential to improve treatment adherence. While these results require further validation in real clinical settings, our study provides a new perspective on how gamification design, through motivation stimulation, emotional management, and focus enhancement, can promote treatment adherence. In the following sections, we will provide an in-depth discussion of the results from two perspectives: behavior during therapy and game experience.

6.1. Behavioral Changes and Effective Treatment

The experimental results demonstrate that FunBreath outperforms conventional games in terms of respiratory behavior-related metrics and fulfillment of player needs, thereby improving both the quality of breathing and adherence with treatment. This supports our hypothesis, **H1**.

6.1.1. Changes in Intrinsic Motivation

FunBreath introduces familiar and engaging entertainment elements into traditional medical scenarios, stimulating children's intrinsic motivation and fostering positive behavioral changes during treatment (Cheng & Ebrahimi, 2023). Participants engaging with FunBreath experienced storyline progression closely tied to their actions. They could proceed through gamified activities at their own pace, effectively meeting their need for autonomy, which further enhanced and sustained their motivation for active participation (Shih et al., 2019).

Moreover, FunBreath skillfully integrates a reward mechanism with narrative elements, satisfying children's needs for autonomy, competence, and relatedness. For instance, some participants noted that experiencing The Three Little Pigs story while playing the game was much more enjoyable than simply watching traditional animations used in nebulization therapy. These responses highlight FunBreath's critical role in enhancing children's intrinsic motivation. Overall, FunBreath's cohesive design, spanning aesthetic, dynamic, and mechanical dimensions, successfully attracts and maintains player engagement (Zichermann & Linder, 2010). Consequently, children's focus naturally shifts away from the negative aspects of the treatment process. This observation aligns with findings from previous research. For example, (Everard, 2004) demonstrated that playful nebulization devices could capture patients' attention, resulting in more effective therapy. Similarly, studies by (Basheti et al., 2007) and (Yanık, 2018) revealed that cartoon-style designs and colorful environments effectively reduce children's fear of unfamiliar settings.

Although FunBreath did not have a significant advantage on the "autonomy" dimension of PENS, probably due to the limited sample size, it was evident that children were able to maintain a high quality of breathing during the experience, autonomously and easily. In contrast, when participants were playing a common game like Tetris, their breathing performance was notably lower compared to the FunBreath condition, suggesting reduced maintenance of effective breathing behaviors. Thus, the significant difference between FunBreath and ordinary games in terms of motivational stimulation and its resulting outcomes supports the later mentioned significant differences in expiratory pressure and respiratory rate between the control and treatment groups.

However, while this study was conducted in a controlled environment, real clinical settings may present additional challenges. For instance, children may encounter unfamiliar medical equipment, discomfort from medication, or emotional distress, which could affect their engagement and motivation. These factors may influence the effectiveness of FunBreath's motivational mechanisms. Future studies are needed to investigate how these real-world conditions impact the system's efficacy and user experience.

6.1.2. Intuitive Breathing Control

Our observations indicate that FunBreath effectively guided children's breathing behavior, achieving significantly higher scores in the "intuitive controls" dimension compared to conventional games. This intuitive interaction design enabled children to naturally control their breathing and perceive its effects, such as blowing flowers and houses. The sense of purpose and immediate feedback within the game fulfilled their need for competence (Gilmore et al., 2015). For instance, one participant mentioned that blowing harder generated stronger winds, which enhanced their self-confidence. This clear sense of control significantly boosted the children's sense of competence, aligning with prior findings that biofeedback-driven visualization can improve users' control over tasks and their sense of self-efficacy (Bitrián et al., 2020; Suh et al., 2018).

During conventional game interventions, children's attention to the game often diverted focus from maintaining effective breathing, resulting in a marked disadvantage in breathing quality. However, while engaging with FunBreath, children were required to sustain high-quality and varied breathing patterns to keep pace with the game's rhythm and challenges. The combination of instructional animations and physiological visual feedback greatly enhanced the game's intuitiveness, allowing children to maintain optimal breathing quality effortlessly. For example, one participant noted that the changing size of the wolf mask in the game prompted them to breathe rhythmically. Similar studies have reported comparable outcomes. For instance, (Barkın et al., 2023) found that therapist-guided, game-based interventions positively influenced motor skill development in children. To some extent, the guiding animations in FunBreath functioned as a virtual therapist, offering therapeutic education and training to children, thereby improving adherence during treatment (Basheti et al., 2007; Yanık, 2018). Although this study did not strictly standardize children's breathing frequency and depth, the game mechanics and researcher guidance encouraged rhythmic breathing and deep breaths, thereby supporting effective breathing behavior.

Overall, FunBreath supports children's sustained, low-burden focus in therapy through intuitive guidance and diverse feedback mechanisms based on meeting the user's need for autonomy, so we encourage researchers and designers to tightly link game manipulation to therapeutic behaviors, which is likely to address the distraction from therapeutic behaviors due to the focus on the game itself (Tang et al., 2023).

6.2. Gaming Experience

6.2.1. Flow State

The treatment group scored significantly higher than the control group on the GUESS dimensions of play engrossment and narratives. Additionally, the PENS measure of immersion indicated a clear advantage for the treatment group, supporting our hypothesis, **H2**.

FunBreath seamlessly integrated behavioral guidance and gameplay mechanics into its storytelling, allowing children to clearly perceive their roles and objectives within the game. From the perspective of self-determination theory, this design facilitated the emergence of flow experiences (Ryan & Deci, 2000). With clear task objectives, children were able to shift their focus away from the negative aspects of the treatment and instead experience the reward of successfully completing challenges. The intrinsic positive emotional value brought by gameplay itself motivated children to pursue enjoyment for its own sake, resulting in deep immersion in the game (Csikszentmihalyi & Csikszentmihalyi, 1992; Csikszentmihalyi et al., 2014). Clearly defined goals represent achievable expectations of outcomes, which enhance motivation, thereby improving engagement and focus (Keller, 1987). For instance, some participants expressed great enjoyment in blowing away the piglets and their houses, to the point where they forgot they were undergoing nebulization treatment. Additionally, the balanced dynamic between challenge difficulty and player ability enabled children to consistently experience the joy of mastery, further enhancing their immersion.

Many participants also found the storylines and character designs in FunBreath highly engaging, effectively supporting role identification during gameplay and thus boosting immersion and competence (Ryan & Deci, 2000). For example, some participants imagined themselves as the Big Bad Wolf while playing. Moreover, the intuitive interactive feedback fostered a sense of control, which reinforced the children's motivation and willingness to engage with the intervention plan (Spillers & Asimakopoulos, 2012). Questionnaire results showed that participants gave high ratings on items such as "I want to continue playing" and "I would like to play again if possible" across multiple standardized instruments (PENS, GUESS, GEQ, and SUS). Additionally, interview feedback reflected children's enthusiasm for continuing the game and their active engagement with the breathing tasks (e.g., P03: *"I want to blow harder to make the little pigs fly farther"*; P08: *"I want to play this game again"*), further enhancing their immersion in the process.

Regarding concerns about potential fatigue, each gameplay session lasted approximately 1–3 minutes, interspersed with animations, with a total duration of around 15 minutes. This alternating structure was intended to reduce continuous cognitive and physical load. Interview feedback indicated that most children remained actively engaged and did not report experiencing fatigue. Nevertheless, future studies should incorporate subjective assessments and physiological monitoring to systematically evaluate fatigue effects over longer treatment courses.

6.2.2. Playability and Aesthetic Experience

The experimental results of this study, based on playability metrics and semi-structured interviews, demonstrate support for both hypotheses (**H3** and **H4**), confirming that FunBreath outperforms ordinary games in terms of usability, playability, and overall user experience evaluation.

First, the intuitive design of FunBreath's guided animations and visual feedback enabled children to quickly grasp the mechanics without additional learning effort, thereby strengthening their belief in successfully achieving the expected behaviors (Bandura, 1982). For instance, some participants noted that the wind animation mirrored their breathing, making the operation feel effortless. The smooth alternation between narrative storytelling and interactive gameplay provided a relaxing transition experience; one participant mentioned how enjoyable it was to blow down houses and then watch the accompanying animations. Moreover, the game's aesthetic elements, such as its exploratory and imaginative space combined with a cartoon-style breathing mask, sparked curiosity and imagination in children, enhancing their sense of immersion and enjoyment. For example, one participant mentioned feeling like they were helping the Big Bad Wolf complete its tasks with every breath. The engaging storyline and goal-oriented role-playing effectively increased players' interest and sustained motivation (Karakul et al., 2024). Lastly, the detailed visual feedback further added to the fun of interaction. For instance, a participant commented on the humor of seeing smoke spiraling like a hula hoop during exhalation, which boosted the game's appeal. These seemingly minor details significantly contributed to creating a game experience that is both enjoyable and therapeutically effective.

Overall, the FunBreath nebulization mask and its associated game designed to enhance children's adherence and user experience in nebulization therapy exhibit significant advantages over standard games. This game design approach and experimental findings contribute theoretically to the field of gamified health interventions and provide valuable insights for practical applications.

6.3. Limitations

Our work aims to enhance children's efficiency and enjoyment of nebulized therapy through gamification. However, there are several limitations: (1) Limited Generalizability: The study participants were all from Shanghai, where children are more exposed to gaming. As a result, the effectiveness and appeal of the FunBreath system may not translate well to other regions with different cultural, socioeconomic, and medical backgrounds, limiting its broader applicability. (2) Short-Term Evaluation: The study primarily assessed the immediate (five-minute) impact of FunBreath on children's compliance and enjoyment during therapy. Without long-term follow-up, it remains uncertain whether these positive effects will persist over time, particularly in sustaining children's interest and consistent therapeutic adherence. (3) Limited validation under respiratory distress: Due to ethical approval, procedural stability, and participant safety considerations, this study did not include children experiencing respiratory distress or strong emotional fluctuations. In such conditions, children may exhibit rapid breathing, anxiety, or crying, which could substantially affect their ability to engage in interactive tasks. Given the representative challenges of these scenarios in real clinical settings, further research is needed to evaluate the system's adaptability and effectiveness under high-stress conditions. (4) Limited ecological validity: This study was conducted in a controlled, simulated environment, where children interacted with the system while wearing a non-medicated mask in a non-clinical setting (i.e., a kindergarten), simulating the basic procedures of nebulized therapy. While this setup ensured safety and procedural stability, it still differs from real clinical scenarios in several key respects. For example, children in hospital settings may encounter unfamiliar medical equipment, discomfort caused by actual medication inhalation, and ongoing intervention or guidance from caregivers or medical staff. These factors may influence children's emotional responses, interaction tolerance, and ability to maintain attention, potentially affecting the system's usability and intervention outcomes in real treatment contexts. Future studies are needed to evaluate the system's adaptability and clinical performance under actual therapeutic conditions, to more comprehensively assess its practical utility.

7. Conclusion

This study introduces FunBreath, an innovative gamified nebulization therapy system designed to reduce children's fear and anxiety during treatment, improve adherence, and enhance the overall experience. By integrating breathing exercises with game mechanics and a familiar storyline, FunBreath effectively promotes behavioral change and reduces treatment discomfort. The immersive experience, driven by engaging characters and visual effects, fosters a state of flow that helps children focus on game objectives, leading to both improved treatment compliance and enjoyment.

Key contributions of this research include the application of the MDA framework to healthcare game design, demonstrating its effectiveness and ability to create enjoyable health interventions. FunBreath not only showcases practicality in improving nebulization mask design but also offers potential for expansion. Its adaptability to different game narratives and customizable form factors makes it a versatile tool for other health intervention applications. By demonstrating how interactive systems can improve both adherence and user experience, this study lays a valuable foundation for future research and development in gamified health technologies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Survey on Children's Nebulization

Table A.3: Questionnaires for children's nebulization: insights from children and parents.

Survey on Children's Nebulization: Insights from Children and Parents

This survey aims to gather insights into children's psychological and behavioral responses during nebulization therapy. The questions below are targeted at both children and their parents. Your participation is greatly appreciated.

Children

1. What is your name?

[Free text input]

2. Are you a boy or a girl?

○ Boy ○ Girl

3. How old are you?

○ 3 years old ○ 4 years old ○ 5 years old ○ years old

4. Do you like using the mask for nebulization?

○ Yes, I like it. ○ It's okay. ○ I don't like it. ○ It makes me scared. ○ I really hate it.

5. What makes you scared when using the mask? (Multiple choice)

☐ Can't breathe during nebulization ☐ The long tubes make you feel afraid
☐ The nebulizer makes you feel scared ☐ Sit still during nebulization
☐ Go to the hospital ☐ The nebulizer emits white smoke
☐ Keep the nebulizer mask on ☐ Put the mask on your face
☐ The nebulizer makes a buzzing sound ☐ [Something else (parents can help write it.)]

6. What do you do when you feel scared? (Multiple choice)

☐ Seek help from doctors ☐ Seek help from parents
☐ Cry and resist ☐ Self-Soothing ☐ [Something else (parents can help write it.)]

Parents

7. How does your child usually behave during nebulization therapy?

○ Performs very well ○ Fairly obedient ○ Sometimes obedient, Sometimes not
○ Consistently very fearful and anxiousll ○ Consistently resistant

8. What do you do when your child feels fear or anxiety during nebulization? (Multiple choice)

☐ Let the child watch cartoons/ play on the phone ☐ Ignore
☐ Remove the nebulizer for a short break ☐ Frequent comforting and persuasion
☐ Tell stories to the child ☐ [Something else]

9. What is most important in designing a game for children during nebulization? (Multiple choice)

☐ Playability ☐ Effectiveness ☐ Anti addiction ☐ Safety
☐ [Something else]

Appendix B. Semi-structured Interview Questions

Table B.4: Questions for semi-structured interview.

Item	**Question**
Introduction	Do you like watching cartoons? Do you like playing games? What kind of games do you like the most?
Overall Experience	What do you think of the smart mask system overall? Do you think the "Three Little Pigs" game is fun? When playing the game, do you feel nervous or relaxed? Do you feel bored while playing this game? When playing the game, do you forget that you are doing nebulization treatment? Does time pass quickly when you play this game? Did you encounter any difficulties while playing the game?
Feedback and Suggestions About the Game	Do you like the story of "The Three Little Pigs"? Do you think this game is simple? Can you understand the breathing guidance rules and the effects of blowing? Do you think the breathing rhythm guidance in the game is appropriate? Is it easy or hard for you to follow the guidance and complete deep breaths? What do you think is the most fun part of this game? Do you like the colors, characters, and visual elements in the game? How do you feel about the destruction effects created by blowing? What other rewards would you like to receive after completing tasks in the game? When you don't complete the breathing correctly, can you adjust based on the system's feedback?
Suggestions on Design	Does the game accurately detect your breathing? Do you like the design of the mask? While playing the game, do you imagine yourself as the little wolf? Do you find the blowing interaction fun? Is the blowing interaction easy for you? What other features would you like to add to make this game better?
Engagement and Satisfaction	How do you think you performed in the game? Would you like to play this game again? Compared to watching cartoons or playing other games, do you prefer this way of doing nebulization treatment? Why do you prefer or not prefer this way of doing nebulization treatment?