GAMES FOR HEALTH JOURNAL: Research, Development, and Clinical Applications
Volume 00, Number 00, 2024

DOI: 10.1089/g4h.2023.0213



# The Impact of Gamified Auditory–Verbal Training for Hearing-Challenged Children at Intermediate and Advanced Rehabilitation Stages

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## Abstract

***Background:*** Auditory–verbal training is essential for children with hearing challenges, and the gamification approach has become a promising direction for improving the rehabilitation experience and effect. However, the specific influence of the gamified training approach on participants at different rehabilitation stages has not been empirically studied, especially in the practical training effect caused by gamified interventions and the varying influence on children with different rehabilitation status.
***Objective:*** This article is thus intended to investigate the following research questions: (1) do the training performances of children at advanced rehabilitation stage differ before and after using the gamified training system? (2) Do the training performances of children at intermediate rehabilitation stage differ before and after using the gamified training system? (3) Do children enjoy the gamified training approach?
***Methods:*** For the purpose, a digital gamified auditory–verbal training system was originally developed, and a series of user experiments were organized. The training performance of 31 hearing-challenged children was assessed, and interviews with six professional therapists were conducted.
***Results:*** It can be found that generally the gamified training approach can effectively facilitate the training experience and help with the basic auditory memory and expression capabilities. Moreover, it is feasible to be applied in practical training due to the high customization of digital training contents, multimodal interactive training means, and highly enjoyable training experience.
***Conclusions:*** Regarding the specific influence, the gamified way can better improve the basic auditory–verbal performance of children at the intermediate stage since the focus is more on the ease of learning and adaption to the training system. While for children at the advanced rehabilitation stage, the precise training and professional training contents are more in demand, it is not easy to achieve quick improvements. These findings and conclusions can provide insights for further explorations and applications of the gamification approach in children's auditory–verbal rehabilitation.
This study was approved by the Institutional Review Board (IRB) of Shanghai Jiao Tong University with the approval number H2022213P.

**Keywords:** Auditory–verbal rehabilitation, Games, Rehabilitation performance, Rehabilitation experience, Hearing-impaired children

## Introduction

Auditory–verbal therapy (AVT) is important for children who are hard of hearing. With the increasing attention to hearing-challenged children's health and education, the possible rehabilitation training methods and supportive services have been widely studied. Moreover, the technology advancements in hearing aids and cochlear implants have

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enabled hearing-challenged children to hear sound to some degree, and thus, a rehabilitation training with auditory and verbal tasks for more effective training effect and enjoyable training experience is better expected.

Looking into the existing rehabilitation training services, they put more focus on the comprehensiveness of training contents and tasks but neglecting the varying hearing states and training needs of children at different rehabilitation stages. Therefore, the training tasks are not fully tailored to fit different children characteristics. Moreover, the current training process is often repetitive and lacks the consideration of attractive and enjoyable task settings, resulting in weak user engagement and training compliance. To tackle the issues above, diverse training theories and modes have emerged. For example, the AVT focuses on teaching children to listen and speak using their residual hearing.[1] The language experience approach is to create a language-rich environment through a gamified way with books, stories, and activities.[2] For individuals with severe hearing loss or those who may not benefit from traditional speech training, augmentative and alternative communication methods, such as communication boards, speech-generating devices, and gamified mobile apps, can facilitate effective rehabilitation.[3] Among them, the gamification theory, which involves game elements (e.g., attractive stories, rewards, interactive tasks, engaging characters) to create a motivating and an enjoyable training environment, has been demonstrated to be effective in strengthening children's learning performance and improving their training experience,[4,5] and has been widely applied in children's education and training products. Therefore, the integration of gamification approach in auditory–verbal training has become a promising direction for hearing rehabilitation.

In this regard, Splingo's Language Universe[6] is an app designed with typical gamification elements such as rewards, interactive games, and engaging characters to encourage children to practice listening, understanding, and responding to spoken language. LiSN & Learn[7] is an auditory training program designed for children with listening difficulties to identify speech sounds and different auditory cues. AngelSound[8] is a computer-based auditory training program that offers interactive exercises to improve speech perception and auditory skills. Although gamification has been explored in these training products, the training effect of such a gamified approach in auditory–verbal rehabilitation has not been empirically examined. Especially, the rehabilitation effect has not been statistically verified, the influence on different rehabilitation stages has not been fully considered, and the insights on the future rehabilitation program have not been clearly revealed.

Therefore, this research is intended to investigate the training effect of gamified auditory–verbal rehabilitation. For the purpose, a gamified auditory–verbal training system was developed, in which training tasks are divided into different challenge levels and tailored to match the training needs of children at different rehabilitation stages. Considering that the children at the initial rehabilitation stage often have more severe hearing loss and are too young to make independent game interactions, the intermediate and advanced rehabilitation stages are more emphasized. Based on the gamified training system, the training evaluation experiments are organized to examine the following: (1) Do the training performances of children at advanced rehabilitation stage differ before and after using the gamified training system, (2) do the training performances of children at the intermediate rehabilitation stage differ before and after using the gamified training system, and (3) do children enjoy the gamified training approach? The findings from this study are expected to contribute to the following: (1) an empirical examination of the training effect of gamified auditory–verbal rehabilitation approach; (2) a detailed comparison of the varying influence of different gamified task settings between intermediate and advanced rehabilitation stages; and (3) practical suggestions for a gamified training program design in hearing-challenged children's rehabilitation and education.

The remaining of the article is organized as follows: The **Related Works** section provides an analysis of typical hearing rehabilitation methods, existing applications of gamification theory in children's training and education, and the current gamified auditory–verbal training cases. Based on the analysis, the deficiency of empirical investigation of the training effect of gamified rehabilitation approach can be identified. In the **Experiment Design** section, the details of experiment design and statistical analysis process are introduced, and in the **Results Analysis** section, the experiment results in training performance and training experience are presented. The possible insights from this research are discussed in the **Discussion** section, and the research is concluded in the **Conclusion** section.

## Related Works

### *Rehabilitation training for hearing-challenged children*

Generally, the rehabilitation process for children with hearing impairment comprises several distinct stages, according to their evolving hearing status and abilities. Early intervention plays a pivotal role, especially for infants and toddlers, aimed at nurturing auditory awareness and language acquisition.[9] As children grow, their rehabilitation advances to more intricate tasks, including auditory discrimination and speech production.[10] These stages are inherently linked to the child's audiological profile, which may include variables such as the nature and extent of hearing loss, utilization of hearing aids or cochlear implants, and the residual hearing capabilities.[9] Along with the rehabilitation progress, children may gradually transition from visual cues to auditory inputs.[11] The specific communication modalities such as sign language or auditory–verbal approaches often need to be selected based on children's preferences and expected rehabilitation outcomes.[12] The individualized feature of these stages further highlights the importance of tailored interventions for the heterogeneous hearing status and needs.

Regarding existing theories of hearing rehabilitation, they normally emphasize a multifaceted approach that integrates auditory, linguistic, and cognitive components.[13,14] The auditory brain plasticity theory underscores the brain's capacity to form the basis for auditory training in response to auditory stimulation.[15] AVT emphasizes natural auditory learning,[1] while auditory-based phonological training targets speech perception and phonemic awareness.[16] Besides the self-training, technological interventions, such as cochlear implants and hearing aids, provide vital auditory inputs, and virtual reality platforms have also been considered to offer immersive listening experiences.[17] Moreover, robot-assisted rehabilitation training products[14] have been developed to teach sign language through triggering children's audio, visual, and tactile feedback. Machine-based automatic assessment of pronunciation[15] has shown advantages in the professional and efficient assessment on the pronunciation quality of words and sentences during unsupervised exercises. Therefore, the selection of an appropriate approach based on children's hearing abilities, training goals, and available resources is particularly important.

Although different techniques and professional tools have been explored, several limitations and challenges still exist. Basically, the distinct training requirements of different rehabilitation stages have not been fully emphasized in existing training products/platforms. The training service, which is not personalized for different hearing capabilities and rehabilitation stages, may discount the practical training effect. Another issue is the user experience, caused by the poor training interface design and the repetitive training task settings.[18] The lack of child-friendly concerns may discourage the constant use of training tools, thereby limiting the potential benefits of the rehabilitation.[19] Moreover, the training compliance is a significant concern in hearing rehabilitation;[20] for example, children with hearing impairment may struggle to reach effective training interactions, leading to weak engagement over time.[21]

### Development and application of gamification theory

To address the challenges of untargeted training service, poor user experience, and training compliance, the integration of gamification approach[22] might be a potential direction to realize the training tailored for different hearing rehabilitation stages and increase the training attraction to improve training experience and effectiveness.

Generally, the development of gamification theory can be traced back to classical educational and psychological theories. One notable work is Jean Piaget's Constructivism,[23] which emphasizes learning through active engagement and the construction of knowledge. Gamification aligns with this theory by providing children with opportunities to explore, experiment, and discover concepts within a playful context. In addition, Lev Vygotsky's Social Development Theory[24] highlights the importance of social interaction and collaboration in learning. In a similar way, gamification leverages social components, such as leaderboards and collaborative challenges, to encourage peer-to-peer interaction and knowledge sharing. Several other theories have also significantly influenced the development of gamification in children's education. Albert Bandura's Social Cognitive Theory[25] emphasizes the role of self-efficacy and motivation in learning with gamification through providing immediate feedback and progressive challenges. B.F. Skinner's Operant Conditioning Theory[26] advocates the use of rewards and reinforcements to shape learning behavior and learning outcomes.

Regarding the applications of gamification, it has shown profound impact on multiple domains in terms of improving user experience and service innovation.[27] It leverages a range of game mechanics and elements such as scoring, leveling, leaderboards, and achievements to establish a meaningful connection between user progress and the game. For example, the integration of scoring and feedback into cognitive tasks can incentivize participants to invest more effort,[28] resulting in improved response time and reduced error rates. Moreover, it is indicated that consistent game narrative and tasks can better attract users to be engaged, further enhancing user experience and outcomes.[29] Especially in children's education, it has been applied into various educational contexts, including formal classrooms, online platforms, and informal learning settings.[30] Specifically, in formal education, gamification techniques are integrated into curricula to enhance engagement and facilitate learning. Scores, badges, and rewards are used to acknowledge children's achievements and motivate progress.[31] Online educational platforms often utilize gamification to create immersive and interactive learning experiences. Virtual worlds, quests, and interactive challenges can provide opportunities for children to explore and apply concepts in engaging ways.

All of these works suggest that gamification can effectively encourage desired learning behaviors and outcomes in children's education and may also be a promising solution for improving the training experience and outcomes in hearing rehabilitation.

### Existing gamified auditory–verbal training systems

For the explorations of gamified auditory–verbal training, a study was conducted to examine the effects of gamification and experiential learning on the mathematics performance of 24 hearing-impaired learners.[32] The researchers utilized the Mathematics Knowledge Check to gather data and revealed that the use of gamification and experiential learning instructional methods had a significant impact on the math performance of hearing-impaired learners. Interviews and surveys were also conducted[33] and found that children with hearing impairments are not exposed to appropriate sign language learning, since traditional sign language textbooks are difficult to decipher due to their static image content. A learning app called i-Sign was accordingly created, which combines simple gamification and multimedia elements, and was evaluated with 91.89% agreements from the respondents on the efficiency and effectiveness of the app learning.

On the contrary, gamified auditory language training platforms and systems are also emerging in the market, including Hear Coach by Starkey,[34] an app developed to offer auditory training games and featured with different levels of difficulties and gamified elements to motivate users to improve their listening skills, and Hearoes[34] providing a series of online games to educate children about hearing health and communication. Similarly, Splingo's Language Universe,[6] Angel-Sound,[8] and LiSN & Learn[7] are all based on the gamification of auditory language training. Besides, virtual reality (VR) games[35] have been developed to enhance children's participation and immersion in rehabilitation training. These games cover sound detection, auditory discrimination, auditory recognition, and auditory comprehension,[36] based on Erber's paradigm of auditory development stages.

Although the gamified approach has been identified as a promising direction and diverse training products and platforms have been explored, the training effect has not been empirically examined.[37,38] An in-depth analysis is worthwhile to reveal the training effectiveness and training experience of gamified auditory–verbal rehabilitation,[39] and shed light on the potential of gamified auditory–verbal training in hearing rehabilitation therapies.

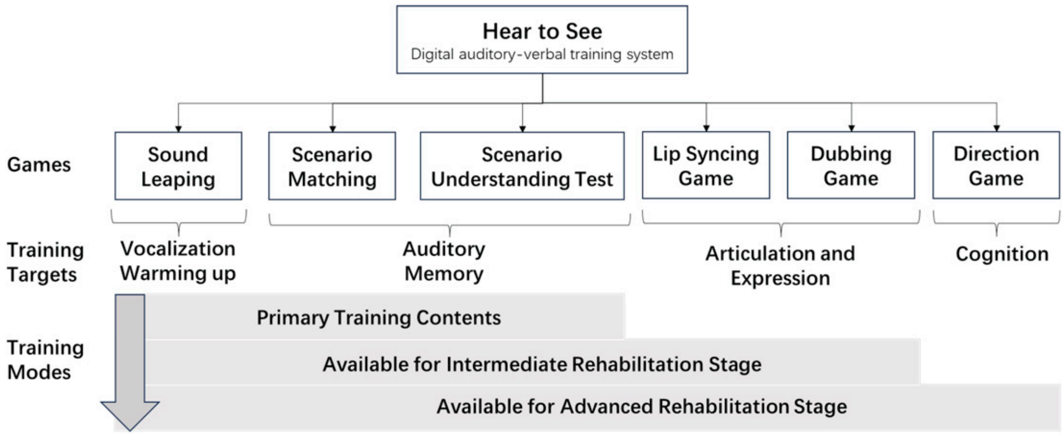


**FIG. 1.** The training game structure.

## Experiment Design

### *The digital rehabilitation game*

An original auditory–verbal training game named "Hear to See" was developed to assist hearing-challenged children between three to six years old. Especially, their skills in sound volume perception, auditory memory, auditory description, articulation abilities, sentence expression, and cognitive abilities will be focused and trained. Figure 1 shows the whole game structure.

Generally, the training modes were tailored to intermediate and advanced rehabilitation stages. Basically, auditory training was arranged as the primary training tasks. Specifically, three games were arranged (as shown in Fig. 2). Sound Leaping is a voice control jumping game, which is for warming up through having participants experience the control of voice volume and duration to increase their training engagement. Scenario Matching is to select the key elements based on the scenario description, and Scenario Understanding Test is to select the right answers based on the scenario understanding. The two games are both for the auditory memory training. The former emphasizes keyword recall, while the latter emphasizes the comprehension of holistic scenarios.

**Vocalization warming up:** In the game of Sound Leaping, phonation volume and time will control the jumping actions of the kitten. Lower sound volumes activate the kitten to move forward, whereas higher sound volumes activate jumping behavior. In addition, the length of the kitten's jumping depends on the phonation time.

**Auditory memory training:** In Scenario Matching, children are required to pair animals with fruits based on the audio descriptions, such as "Please put the lion besides the watermelon." In Scenario Understanding Test, children are asked to pick the correct fruits based on audio cues, such as "It is round, and in red color."

**Articulation and expression training (Fig. 3):** In Lip-syncing Game, children need to imitate the mouth position for the pronunciation of certain vocabularies. A standard mouth position will be shown on the screen, and the children just need to follow and pronounce. The camera will record the face of the participants in real time, and the facial recognition technology of OpenCV will be applied to compare the differences of the mouth position between participants and standard patterns. In the Dubbing Game, longer sentences will be played, and the participants need to repeat the sentences and describe the scenes. The voice recognition technology of Baidu AI will be applied to recognize if the articulation of the participants is correct. These two games contribute to the training of articulation and expression abilities.

**Cognitive training (Fig. 4):** In Direction Game, children control the movements of the kitten by correctly pronouncing "up," "down," "left," or "right" to reach the target endpoint as quickly as possible. Through the game, their cognitive intelligence in spatial and timing sense can be trained.

In the training system, the gamification elements of narrative storytelling, rewarding principles, interactive engagement, and visual characters were effectively integrated. To explain, vibrant and high-saturation colors have been

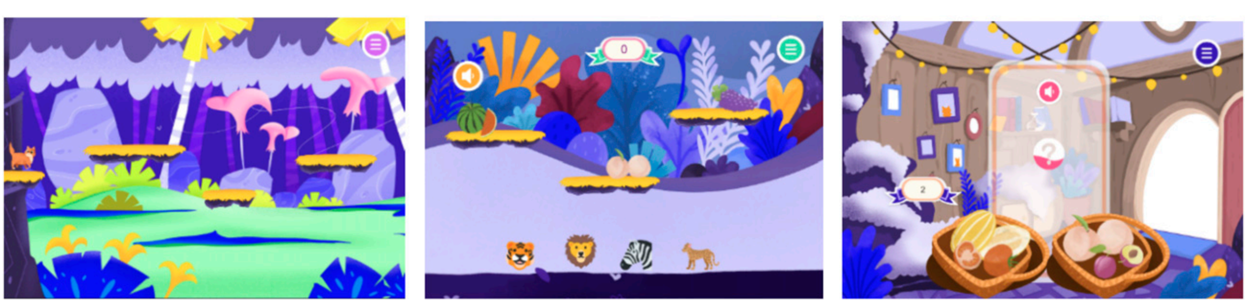

**FIG. 2.** Interfaces of primary training games (from left to right: Sound Leaping, Scenario Matching, and Scenario Understanding Test).


**FIG. 3.** Game interfaces of articulation and expression training (from left to right: Lip-syncing game, and Dubbing game).

strategically incorporated into the visual elements. A narrative story line, for example, a cat chatting with a lion, was arranged to invoke children's intuitive memory and imagistic thinking to enhance training task connections and engagements. Based on children's training performance, the correct responses will get positive visual animations, such as twinkling stars and vibrations, reinforcing a sense of accomplishment and progress; while incorrect responses will get a gentle encouragement, such as "Try again," to avoid frustration and create a positive learning atmosphere. Furthermore, the integration of multimodal interactions through auditory, visual, and verbal cues can further foster children's curiosity and interests and create a cohesive learning experience.

### *Participants*

A total of 31 preschool children aged between three to six years old undergoing different rehabilitation stages at the Ren'ai Rehabilitation Center in Hangzhou were recruited as participants. As mentioned above, children in the early stage of hearing rehabilitation are too young to independently complete the rehabilitation training, and thus, only children at the intermediate and advanced rehabilitation stages were involved. Specifically, 15 of them are in the intermediate stage, and the other 16 participants are in the advanced stage. Regarding the gender distribution, 17 of them are boys and 14 are girls. All the participants are healthy except of hearing, and informed consent was obtained from their guardians and the rehabilitation center. The experiment has received approval from the Institutional Review Board for Human Research Protections of the authors' university. Meanwhile, six therapists in this center were also invited to assist with the experiment.

### *Experiment environment setting*

Participants in the same rehabilitation stage take the experiments in the same experiment room at the Ren'ai Rehabilitation Center, where they regularly take the training. It is to minimize the unfamiliarity and anxiety feelings of the children. Each experiment room was assigned with three roles: the experimenter, the participant, and the teacher of this rehabilitation center (Fig. 5a). Since these participants are three- to six-year-old children, the teacher can provide emotional trust and support to them, helping them take the experiment naturally. During the formal experiment, the teacher would be just there, and the participants need to complete the experiment independently. The guardians can observe the whole experiments outside of the room.

A fixed computer (Macbook2020) with 13.3 inches and $2560 \times 1600$ resolution and macOS 13.0 operation system was set for the rehabilitation game (Fig. 5b). Additional recording cameras were set to record the participants' facial expressions, lip movements, and operation behaviors during the experiment. Once the experiment begins, the screen recording and the participant recording start simultaneously.


**FIG. 4.** Direction Game interfaces.


**FIG. 5.** Experiment environment (a. Experimenting scenes; b. Experiment devices setting).

### Experiment procedures

The whole experiment lasts for two weeks. The training frequency was set referring to the current training plan for intermediate- and advanced-rehabilitation-stage children of the center, which is once a week. Therefore, the participants take the gamified training every week, and their training performance will be compared before and after the experiment. To be noted, tasks for the same training game will be offered in different designs. For example, different animals and fruits will be given for Scenario Matching. The task order will be randomly assigned for the same training game during each experiment.

Regarding the experiment process, it covers three main stages (as shown in Fig. 6). The first stage is the preparation. The experiment purpose, procedures, and guidelines were explained to the participants and their parents. With the assistance of the therapist in the rehabilitation center, basic information of the participants was recorded, and their hearing ability assessed. For the purpose, the acknowledged professional assessment tools of "Brief Evaluation Form for Auditory Rehabilitation of Hearing-Impaired Children,"[40] "Brief Assessment Form for Articulation and Phonological of Hearing-Impaired Children,"[41] "Brief Evaluation Form for Language Abilities Assessment of Hearing-Impaired Children,"[42] and "Speech Intelligibility Grading Questionnaire"[43] were used. With the primary introduction and hearing assessment, the participants will be familiarized with the game content and rules and can try the necessary operations.

During the formal experiment, participants were assigned with training games matching with their rehabilitation stage. For example, the children at the intermediate rehabilitation stage need to try the Warming up, Auditory memory, and Articulation and expression games. Correspondingly, the children at the advanced rehabilitation stage need to try all the games from Warming up to Direction recognition. For each game, 5 minutes were assigned for participants to practice, so that 20–25 minutes in total were spent for each round of training.

The third stage is the postexperiment assessment. After the training of two weeks, participants' hearing abilities will be reassessed with the assistance from the therapists using the abovementioned assessment tools. Besides, the User Experience Questionnaire (UEQ) is used to evaluate the training experience with this gamified rehabilitation system. Moreover, in-depth interviews are arranged to collect the comments and suggestions from the participants (their guardians) and the therapists in the rehabilitation center.

The whole experiment process of all participants will be recorded. Considering that the Sound Leaping game is a warm-up game, no data analysis will be performed. The specific data recorded during the training tasks are summarized as follows:

- ***Scenario Matching***: Participants' completion time, and the number of times the scenario description has been played until the participants can correctly complete the training task.

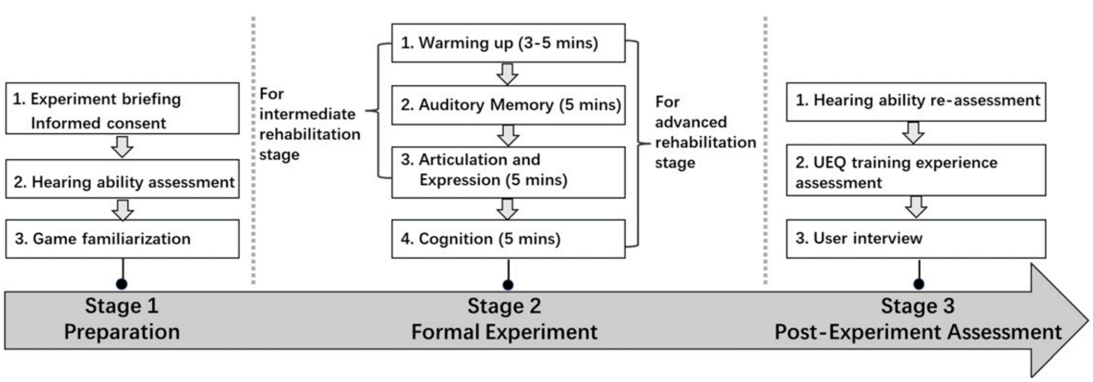


**FIG. 6.** Experiment process and specific procedures.

- ***Scenario Understanding Test*:** Participants' completion time, scores, the number of times the scenario description has been played, and the incorrect answers from participants.
- ***Lip-syncing*:** Participants' facial expressions (especially the mouth position), the number of times the audio description has been played, the completion time, the number of pronunciation errors, and specific errors in sound and mouth positions.
- ***Dubbing Game*:** Participants' completion time, the number of times the audio description has been played, the number of pronunciation errors, and specific errors in sound and intonation.
- ***Direction Game*:** Participants' completion time and pronunciation errors.

With the experiment data recorded, participants' training performance will be compared before and after experiment, to evaluate whether the gamified training approach can effectively improve their auditory–verbal performance and the training performance. For the purpose, *t*-tests will be mainly used to examine the differences in training performance before and after the gamified training intervention, and the comparison of the varying influences caused by the gamified training approach between intermediate and advanced rehabilitation stages. Besides, the experience rating scales and interview feedback will be analyzed to investigate if the gamified training approach is emotionally satisfying and enjoyable.

## Results Analysis

In this section, the three questions will be emphatically analyzed: (1) Do the training performances of children at advanced rehabilitation stage differ before and after using the gamified training system? (2) Do the training performances of children at the intermediate rehabilitation stage differ before and after using the gamified training system? (3) Do children enjoy the gamified training approach? For the purpose, the data collected in the **Experiment procedures** section are analyzed, and the training performance will be accordingly investigated. Particularly, an analysis strategy consisting of auditory memory evaluation, articulation and expression evaluation, direction cognition evaluation, training engagement evaluation, and training experience evaluation was proposed. Specifically the following:

**Auditory Memory Evaluation:** The data in Scenario Matching and Scenario Understanding Test will be integrated to evaluate the auditory memory ability. For the purpose, the game performance data of task completion time and error rate will be jointly considered to evaluate the game performance level, which will be directly compared before and after the training.

**Articulation and Expression Evaluation:** The performance data in task completion time, the number of times the audio description has been played, and the error rate of Lip Syncing and Dubbing games will be jointly considered to evaluate the training performance level and will be compared before and after the training. Moreover, the assessment tools of "Brief Evaluation Form for Auditory Rehabilitation of Hearing-impaired Children," "Brief Assessment Form for Articulation and Phonological Rehabilitation of Hearing-impaired Children," and "Speech Intelligibility Grading Questionnaire" were used to professionally assess the children's articulation and expression ability. Particularly, children's ability in auditory description with given hints, auditory description without any hints, and the ability to speak clearly will be assessed.

**Direction Cognition Evaluation:** The performance data of Direction game, such as completion time, will be compared before and after the training.

**Training Engagement Evaluation:** The assessment tool of "Brief Evaluation Form for Language Abilities of Hearing-impaired Children" was used to professionally examine if children have effective training engagement. For example, the performance of using language to express (e.g., describe, make comments, narrative skills), using language as a tool to query, demand, and order, using language to coordinate during the tasks, and enjoying the language as a kind of entertainment are measured.

**Training Experience Evaluation:** The UEQ[44] scale was used, and the dimensions of "attractiveness," "perspicuity," "efficiency," "stimulation," and "novelty" will be rated to represent the subjective feedback of participants on this training system.

Paired t-test was adopted to examine the difference before and after the training. Normal distribution tests were performed for every round of analysis, and it shows that t-tests can be applied. The SPSS Statistics v29 software was used as the analysis tool.

### *Does the training performance of children at advanced rehabilitation stage differ before and after using the gamified training system?*

Following the analysis strategy explained above, children's training performance was investigated in terms of different auditory–verbal capabilities. The results of Auditory memory, Articulation and expression, and Training engagement are shown in Table 1.

Based on Table 1, it can be observed that significant differences exist in "Articulation performance" and "Language for expression" dimensions. It suggests that the gamified training has positive effect on enhancing speech abilities of children at the advanced rehabilitation stage. However, in "Auditory memory," "Auditory description with hints," and "Auditory description without hints" dimensions, the impact of gamified training is not statistically important. It can be understood that children at the advanced rehabilitation stage already possess basic auditory–verbal capabilities, and thus, noticeable improvements in auditory aspects are not easy to achieve. Similarly, no significant differences were observed in "Speech intelligibility," "Language as a game tool," and "Language for coordination." For these dimensions, children are required to have higher skills to express them clearly and use language or speech as a functional tool. Therefore, long-time training is often necessary, and the training during this experiment may not be enough to influence these dimensions.

Regarding the specific training games, several tasks were performed by participants. As explained in the **Experiment procedures** section, different tasks are prepared for the same training game. During the five-minute training for each game, the participants can practice several tasks. Apart from

Table 1. Paired *t*-Test for Training Performance of Children at Advanced Rehabilitation Stage

| *Evaluations* | *Mean ± standard deviation* | | *Difference value* | t | P |
|---|---|---|---|---|---|
| | *Before experiment* | *After experiment* | | | |
| Auditory memory | | | | | |
| Auditory memory[a] | 4.56 ± 0.51 | 4.75 ± 0.45 | −0.19 | −1.861 | 0.083 |
| Articulation and Expression | | | | | |
| Articulation performance[a] | 20.88 ± 3.98 | 22.38 ± 2.68 | −1.5 | −3.674 | 0.002** |
| Auditory description with hints[b] | 3.69 ± 0.48 | 3.88 ± 0.34 | −0.19 | −1.861 | 0.083 |
| Auditory description without hints[b] | 2.75 ± 0.77 | 2.88 ± 0.72 | −0.13 | −1.464 | 0.164 |
| Speech intelligibility[b] | 4.44 ± 0.51 | 4.63 ± 0.50 | −0.19 | −1.861 | 0.083 |
| Training Engagement | | | | | |
| Language for expression[b] | 7.31 ± 1.30 | 7.63 ± 0.96 | −0.31 | −2.611 | 0.020* |
| Language as game tool[b] | 7.63 ± 1.41 | 7.69 ± 1.30 | −0.06 | −1 | 0.333 |
| Language for coordination[b] | 7.56 ± 1.31 | 7.63 ± 1.31 | −0.06 | −1 | 0.333 |

[a]Represents the analysis results obtained based on game performance data.
[b]Represents the analysis results obtained based on the auditory–verbal assessment.
*$P < 0.05$, **$P < 0.01$.

the comparison before and after the whole training, the performance of different rounds of training tasks will also be investigated. For Lip Syncing game, the performance data are shown in Table 2. To be noted, since the task order is random for two rounds of training, only the same tasks will be compared. Different tasks are marked using different letters, such as Task A, B, and C.

Based on Table 2, it is clear that generally the completion time and task errors are improved through two rounds of training. Particularly, the task errors (i.e., inaccurate pronunciations) have significantly reduced. Since the bias caused by repeated training was considered in the random arrangement of tasks for each participant, it may suggest that the training system can effectively improve the training effect.

For Dubbing game, the performance data are shown in Table 3.

For Dubbing games, the completion time of Task A and Task C significantly decreased. However, no significant differences were observed in terms of task errors. This is possibly caused by their increasing familiarity with the training game. However, the training difficulty remains similar to them despite two rounds of training. The dubbing tasks require participants to have a good understanding of the narrative story, and then describe the scene correctly. The proficiency needed to successfully complete this task is actually high, and the limited training period and the training just focusing on the auditory–verbal training is not enough to support the implementation of this tasks.

For Direction game, the performance data are shown in Table 4.

In the Direction game, a notable improvement in completion time was observed. It indicates that children became more proficient in recognizing direction targets and pronouncing directional cues. The training approach can effectively improve their direction cognition performance.

### *Do the training performances of children at intermediate rehabilitation stage differ before and after using the gamified training system?*

Based on the paired *t*-test between pre- and postexperiment results, it shows that hearing-challenged children at the intermediate rehabilitation stage achieved improvements in auditory memory, articulation, and expression performances.

As shown in Table 5, "Auditory memory" was significantly improved. Different from children at the advanced rehabilitation stage, the auditory–verbal capability of such participants is still in a preliminary stage. Therefore, the training appears very helpful to enhance their basic auditory abilities. Moreover, the dimensions of "Articulation performance," "Auditory description with hints," and "Language for

Table 2. Paired *t*-Test for Training Performance of Children at Advanced Rehabilitation Stage in Lip Syncing Game

| *Evaluation metrics* | *Mean ± standard deviation* | | *Difference value* | t | P |
|---|---|---|---|---|---|
| | *The 1st training* | *The 2nd training* | | | |
| Completion time of Task A | 7.31 ± 4.25 | 4.50 ± 0.97 | 2.81 | 2.505 | 0.024* |
| Errors in Task A | 1.13 ± 1.50 | 0.19 ± 0.40 | 0.94 | 2.7 | 0.016* |
| Completion time of Task B | 10.31 ± 14.08 | 4.50 ± 1.37 | 5.81 | 1.767 | 0.098 |
| Errors in Task B | 1.88 ± 2.36 | 0.31 ± 0.60 | 1.56 | 2.854 | 0.012* |
| Completion time of Task C | 6.69 ± 6.49 | 3.88 ± 0.89 | 2.81 | 1.733 | 0.104 |
| Errors in Task C | 1.19 ± 1.52 | 0.31 ± 0.60 | 0.88 | 2.333 | 0.034* |

*$P < 0.05$, **$P < 0.01$.

Table 3. Paired *t*-Test for Training Performance of Children at Advanced Rehabilitation Stage in Dubbing Game

| *Item* | *Mean ± standard deviation* | | *Difference value* | t | P |
|---|---|---|---|---|---|
| | *The 1st training* | *The 2nd training* | | | |
| Completion time of Task A | 57.94 ± 52.29 | 45.00 ± 37.84 | 12.94 | 2.97 | 0.010** |
| Errors of Task A | 1.56 ± 1.86 | 1.88 ± 2.13 | −0.31 | −1.431 | 0.173 |
| Completion time of Task B | 29.19 ± 52.43 | 15.88 ± 15.50 | 13.31 | 1.361 | 0.194 |
| Errors of Task B | 0.75 ± 1.57 | 0.75 ± 1.24 | 0 | 0 | 1 |
| Completion time of Task C | 80.19 ± 53.02 | 67.69 ± 43.09 | 12.5 | 3.619 | 0.003** |
| Errors of Task C | 3.06 ± 2.52 | 3.06 ± 2.17 | 0 | 0 | 1 |

*$P < 0.05$, **$P < 0.01$.



expression" significantly improved, which further demonstrates that the gamified training can effectively enhance their articulation and expression performance.

However, "Auditory description without Hints" shows no significant difference. The dimension appears more challenging for children at the intermediate rehabilitation stage to get quick improvement. Besides, no significant differences were observed with "Speech intelligibility," "Language as a game tool," and "Language for coordination." Similar with children at advanced rehabilitation stage, such dimensions require better mastering of the functional use of language and are not easy to be influenced by limited training. Therefore, the influence on participants' effective training engagement is limited.

For Lip syncing game, the performance data are shown in Table 6. It can be found that there is a significant decrease in completion time for all the tasks, which suggests that the training performance can be effectively improved in mouth position learning and the pronunciation of single consonants. However, the influence on task error is not very clear, which indicates that the training is not useful enough to improve the training effect.

For Dubbing game, the performance data are shown in Table 7. Significant influence was observed only on the completion time of two tasks. As mentioned above, Dubbing games have higher requirements on users' scenario understanding and descriptive expression abilities. It is difficult for the children at intermediate rehabilitation stage to achieve marked improvement in their training performance.

### *Do children enjoy the gamified training approach?*

The tool UEQ (https://www.ueq-online.org/) was adopted to measure the user experience from five dimensions, that is, "attractiveness," "perspicuity," "efficiency," "stimulation," and "novelty." Based on the rating scores, five evaluation levels can be labeled, including "Excellent," "Good," "Above Average," "Below Average," and "Bad." With the ratings from 31 participants, the post-training UEQ results are presented in Table 8 and Figure 7. It can be seen that the scores of "attractiveness" and "novelty" of the training system are 2.17 and 2.15, labeled as "Excellent," indicating that the gamified training approach is very attractive and innovative to participants. Besides, the scores of "perspicuity," "efficiency," and "stimulation" are 1.79, 1.68, and 1.60, which are positioned as "Good," implying that users have positive experience in the practical use of this system. Therefore, users have generally a very positive evaluation on the gamified training approach.

Moreover, interviews were conducted with the 31 participants and their parents, and six therapists in the rehabilitation center. Compared with traditional classroom teaching, they expressed stronger interest and higher preference on the gamified system.

For the 15 participants at the intermediate rehabilitation stage, the majority enjoy "Sound Leaping" the most. As a warm-up process, it can effectively trigger participants' engagement and enhance their training acceptance. In terms of auditory training, they also expressed very positive experience with Scenario matching and Scenario understanding test and commented that they have higher enthusiasm to take training with the gamified system. However, Lip syncing and Dubbing were less favored by them, due to the high requirement for precise pronunciation.

For participants at advanced rehabilitation stage, the Direction game was highly rated by most participants, followed by the Dubbing game. Such training can help them with the learning of simple sentences and the precise control and use of pronunciation via an enjoyable way. However, the auditory training of Scenario matching and Scenario understanding test is less favored, since the training content is basic, and the training tasks appear too repetitive to them.

Table 4. Paired *t*-Test for Training Performance of Children at Advanced Rehabilitation Stage in Direction Game

| *Direction cognition* | *Mean ± standard deviation* | | *Difference value* | t | P |
|---|---|---|---|---|---|
| | *The 1st training* | *The 2nd training* | | | |
| Completion time | 141.50 ± 63.02 | 106.50 ± 26.26 | 35 | 3.292 | 0.005** |

*$P < 0.05$, **$P < 0.01$.

Table 5. Paired *t*-Test for Training Performance of Children at Intermediate Rehabilitation Stage

| Evaluations | *Mean ± standard deviation* Before experiment | After experiment | Difference value | t | P |
|---|---|---|---|---|---|
| Auditory memory | | | | | |
| Auditory memory[a] | 3.67 ± 0.49 | 4.00 ± 0.53 | –0.33 | –2.646 | 0.019* |
| Articulation and Expression | | | | | |
| Articulation performance[a] | 16.20 ± 1.57 | 18.93 ± 4.28 | –2.73 | –4.771 | 0.000** |
| Auditory description with hints[b] | 2.73 ± 0.59 | 3.07 ± 0.70 | –0.33 | –2.646 | 0.019* |
| Auditory description without hints[b] | 1.20 ± 0.86 | 1.33 ± 0.72 | –0.13 | –1.468 | 0.164 |
| Speech intelligibility[b] | 3.47 ± 0.74 | 3.53 ± 0.64 | –0.07 | –1 | 0.334 |
| Training Engagement | | | | | |
| Language for expression[b] | 5.00 ± 1.81 | 5.60 ± 1.68 | –0.6 | –3.154 | 0.007** |
| Language as game tool[b] | 5.60 ± 2.29 | 5.73 ± 2.15 | –0.13 | –1.468 | 0.164 |
| Language for coordination[b] | 5.40 ± 1.76 | 5.53 ± 1.85 | –0.13 | –1.468 | 0.164 |

[a]Represents the analysis results obtained based on game performance data.
[b]Represents the analysis results obtained based on the auditory–verbal assessment.
$*P < 0.05$, $**P < 0.01$.



Based on the interview among participants at the intermediate and advanced rehabilitation stages, it is clear that for different rehabilitation stages, the suitable training approach is different. Therefore, it is very important to provide a multitype and multilevel training content to fit different rehabilitation needs.

For the therapists, they all agreed that the gamified training approach can greatly strengthen children's training intention and increase their training compliance. Especially compared with classroom teaching, the gamified training approach shows clear advantage in the interactive training means and vivid construction of narrative training scenario. Meanwhile, they pointed out possible improvements, such as the adaption to colloquial expression in technical recognition of participants' pronunciation and mouth positions, and make a good balance between auditory–verbal training and the gamified visualization, avoiding too many visual distractions. In addition, more elaborate distinction in training contents and task difficulties can be considered (e.g., setting more difficulty levels and training types) to further meet the training characteristics of different rehabilitation stages.

Based on the UEQ results and interview analysis, it can be reached that the gamified training approach is attractive to participants and can effectively improve their training performance. However, the specific influence of the gamified approach on training performance varies among different rehabilitation stages. Therefore, it is important to tailor the training tasks and gamification elements to fit different hearing states.

## Discussion

### *Comparative impact of gamification on auditory–verbal abilities by rehabilitation stage*

Through comparing children's training performance between advanced and intermediate rehabilitation stages (Tables 1 and 5), it can be found that the gamified approach generally shows more effective influence on children at the intermediate rehabilitation stage, especially in the basic auditory (i.e., auditory memory) and verbal (i.e., articulation, auditory description with hints, language for expression) capabilities. It can be understood that for children at the preliminary rehabilitation stage, the training measure, which can attract them to practice more, may lead to obvious improvements. However, for the children at advanced rehabilitation stage, it is not easy to achieve quick improvement just through the gamification of the training content.

Looking into the specific training games, a significant influence can be observed in the error rate for the children at advanced rehabilitation stage in the Lip-syncing game (Tables 2 and 6); however, the influence is more presented in the completion time for children at the intermediate rehabilitation stage. It strongly indicates that children at the advanced stage are more targeted at the precise pronunciation, and

Table 6. Paired *t*-Test for Training Performance of Children at Intermediate Rehabilitation Stage in Lip Syncing Game

| Item | *Mean ± standard deviation* Before the experiment | After the experiment | Difference value | t | P |
|---|---|---|---|---|---|
| Completion time of Task A | 16.80 ± 14.01 | 9.20 ± 5.23 | 7.6 | 3.111 | 0.008** |
| Errors of Task A | 1.47 ± 1.81 | 0.80 ± 1.01 | 0.67 | 2.197 | 0.045* |
| Completion time of Task B | 4.80 ± 2.14 | 3.73 ± 0.59 | 1.07 | 2.256 | 0.041* |
| Errors of Task B | 0.07 ± 0.26 | 0.13 ± 0.52 | –0.07 | –0.435 | 0.67 |
| Completion time of Task C | 8.47 ± 7.39 | 4.67 ± 1.05 | 3.8 | 2.153 | 0.049* |
| Errors of Task C | 0.40 ± 0.63 | 0.27 ± 0.59 | 0.13 | 1.468 | 0.164 |

$*P < 0.05$, $**P < 0.01$.

Table 7. Paired t-Test for Training Performance of Children at Intermediate Rehabilitation Stage in Dubbing Game

| *Item* | *Mean ± standard deviation* | | *Difference value* | t | P |
|---|---|---|---|---|---|
| | *The 1st test* | *The 2nd test* | | | |
| Completion time of Task A | 78.00 ± 37.18 | 72.07 ± 33.54 | 5.93 | 1.771 | 0.098 |
| Errors of Task A | 4.13 ± 2.47 | 3.73 ± 1.83 | 0.4 | 1.702 | 0.111 |
| Completion time of Task B | 117.40 ± 86.44 | 98.87 ± 87.39 | 18.53 | 2.875 | 0.012* |
| Errors of Task B | 4.80 ± 2.88 | 4.53 ± 2.77 | 0.27 | 1.293 | 0.217 |
| Completion time of Task C | 66.27 ± 53.79 | 44.53 ± 28.82 | 21.73 | 2.311 | 0.037* |
| Errors of Task C | 3.33 ± 3.15 | 2.67 ± 2.44 | 0.67 | 1.128 | 0.278 |

$^*P < 0.05$, $^{**}P < 0.01$.

children at the intermediate stage are still adapting to new training measures. The professional training content should be differentiated for meeting the distinct training purposes. In this regard, the performance of Scenario understanding test was extendedly analyzed (Tables 9 and 10). Through a comparison, it is extremely clear that children with intermediate auditory–verbal capabilities can achieve better improvements. The Scenario understanding test is helpful to change the training performance of children at intermediate rehabilitation stage but appears not effective enough to influence children at the advanced stage. The finding is consistent with the above that the more complex and professional training content may better fit the children at the advanced stage, and the specific gamification methods and elements should match with participants' skill levels well.

For Dubbing game, the influence only exits in task completion time no matter for children at advanced stage or intermediate stage (Tables 3 and 7). It implies that the gamification may bring about more complex factors, such as the more complex training visualization and understanding, which may require supportive capabilities to complete, not just relying on auditory–verbal aspects. Therefore, it is challenging for children to adapt in short time and not easy to reach effective training effect.

For Direction game, it is only prepared for the children at advanced rehabilitation stage to train their direction cognition ability. The training performance data and the post-training evaluations all revealed that children enjoy such training measure and can achieve effective improvement in spatial perception and orientation. It suggests that the cognitive training may be suitable in the gamified way, and it can be further considered to strengthen the auditory–verbal training supplying cognitive contents.

Moreover, it is interesting to find that the significant differences can be more easily observed in the dimensions based on game performance data, which are directly recorded during the game practicing. Most of the dimensions derived from the professional assessment tools, which need to be assessed by professionals, are not showing meaningful influence. It indicates that the training performance can be changed along with the training, but the real hearing ability is not easy to achieve effective improvements. The gamified way is suitable to the capability that can be changed in a short time. However, for the comprehensive language competence, a long-term training is still needed to make further validation.

### *Feasibility of the gamified auditory–verbal training approach*

Based on the joint analysis of participants' and therapists' interviews, it can be reached that the gamified approach is better preferred compared with traditional training, and it contains great potential to practically help hearing-challenged children to realize self-training. Particularly, the high customization of the gamified training approach can facilitate the feasibility in supporting children with different hearing states. It can effectively motivate children to exercise, and meanwhile, the digital training content can be flexibly tailored and updated to meet different training purposes. Moreover, the technical implementation of sound detection and visual recognition is adaptable to various sounds and visual characteristics, which further enhances the technical feasibility of the training system.

Regarding the training content, it is highly consistent with the professional training materials. Based on the training textbooks and references, proper gamification elements were applied to create a multimodal training environment. Therefore, it ensures basic professionality, and provides additional value in improved training experience. Moreover, the gamification design should be careful to provide attractive training tasks, and meanwhile avoid too much distraction caused by unnecessary gamification elements.

Generally, clear advantages can be identified with the gamified auditory–verbal training approach. It can assist with the enjoyable training experience and enhanced training

Table 8. User Experience Questionnaire Evaluation Results

| *Scale* | *Mean* | *Comparison with benchmark* | *Interpretation* |
|---|---|---|---|
| Attractiveness | 2.17 | Excellent | In the range of 10% best results |
| Perspicuity | 1.79 | Good | 10% of results better, 75% of results worse |
| Efficiency | 1.60 | Good | 10% of results better, 75% of results worse |
| Stimulation | 1.68 | Good | 10% of results better, 75% of results worse |
| Novelty | 2.15 | Excellent | In the range of 10% best results |

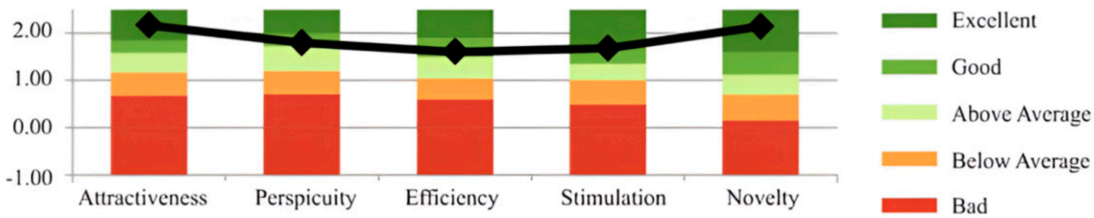


**FIG. 7.** Benchmark bar chart of User Experience Questionnaire results.



compliance. However, varying impacts should be considered during the gamification design of training tasks for children at different rehabilitation stages. Proper gamification should respect participants' skill levels, subject to professional training contents, avoid too much visual distractions, and adapt to different pronunciation behaviors. These insights also shed light on the promising direction of gamified auditory–verbal training as a valuable rehabilitation tool for hearing-challenged children.

## Conclusion

This study is intended to empirically examine the influence of gamified auditory–verbal training on children at different rehabilitation stages, particularly in terms of (1) the influence of gamified auditory–verbal training on the training performance of children at the advanced rehabilitation stage; (2) the influence of gamified auditory–verbal training on the training performance of children at the intermediate rehabilitation stage, and (3) the training experience of the gamified approach. Based on user experiments with 31 hearing-challenged children, the results show that the gamified training can generally bring positive influence on basic auditory memory, articulation and expression capabilities, training engagement, and training experience. For children at the intermediate rehabilitation stage, the gamification that can attract them and trigger their training motivation is more important. Therefore, it can influence their training completion performance relatively easily. However, for children at the advanced rehabilitation stage, gamification is required to be proper with reasonable gamification elements, and professional with precise practice contents. Therefore, it is not easy to improve their training performance in a short time.

Based on this work, helpful insights can be achieved that the incorporation of gamified elements in the auditory–verbal training program can be an effective way to improve the training performance and training experience. Especially for children, their training motivation and compliance can be significantly enhanced. Regarding the gamified training program design, training tasks should be tailored for different rehabilitation statuses. For example, a more engaging strategy, such as attractive storylines, rewards, and interactive tasks, can be provided for children at intermediate stages to stimulate their training motivation, and more professional training tasks with a reliable feedback mechanism can be prepared for children at the advanced stage to upgrade their communication skills. In addition, the gamified training approach contains clear potential to further support the current auditory–verbal rehabilitation system, owing to the high customization of digital training contents, the multimodal interactive means, and the enjoyable training experience.

This work is expected to contribute to the following: (1) the empirical examination of the influence of gamified auditory–verbal training on the training performance of hearing-challenged children at different rehabilitation stages; (2) an in-depth evaluation of the training experience and training feasibility of the gamified auditory–verbal training system; and (3) valuable insights on the further explorations of the gamification approach in hearing-challenged children's rehabilitation and education.

However, there are still some limitations of this work. For example, the sample size of 31 hearing-challenged children and six therapists is still limited. The training period of two weeks is relatively short, due to the time limitation and the consideration of not interfering too much in the normal training at the rehabilitation center. In future work, a larger sample size will be considered to achieve a more reliable statistical analysis, and the training will last for a more effective period to validate the lasting training effect. More detailed investigations of different gamification elements on

Table 9. Paired *t*-Test for Training Performance of Children at Advanced Rehabilitation Stage in Scenario Understanding Test Game

| *Game performance* | *Mean ± standard deviation* | | *Difference value* | t | P |
|---|---|---|---|---|---|
| | *Before the experiment* | *After the experiment* | | | |
| Completion time of Task A | 13.00 ± 5.74 | 13.00 ± 4.55 | 0 | 0 | 1 |
| Completion time of Task B | 19.56 ± 16.35 | 14.00 ± 7.28 | 5.56 | 2.014 | 0.062 |
| Completion time of Task C | 12.81 ± 6.36 | 11.94 ± 3.59 | 0.88 | 0.76 | 0.459 |
| Completion time of Task D | 11.50 ± 3.46 | 12.50 ± 3.10 | −1 | −3.464 | 0.003** |
| Completion time of Task E | 15.88 ± 12.27 | 12.38 ± 3.98 | 3.5 | 1.475 | 0.161 |

*$P < 0.05$, **$P < 0.01$.

Table 10. Paired *t*-Test for Training Performance of Children at Intermediate Rehabilitation Stage in Scenario Understanding Test Game

| *Game performance* | *Mean ± standard deviation* | | *Difference value* | t | P |
|---|---|---|---|---|---|
| | *Before the experiment* | *After the experiment* | | | |
| Completion time of Task A | 20.87 ± 13.29 | 15.53 ± 6.35 | 5.33 | 2.442 | 0.028* |
| Completion time of Task B | 23.20 ± 10.88 | 18.40 ± 6.78 | 4.8 | 3.091 | 0.008** |
| Completion time of Task C | 17.93 ± 11.66 | 13.87 ± 6.49 | 4.07 | 2.8 | 0.014* |
| Completion time of Task D | 20.73 ± 13.42 | 15.60 ± 6.27 | 5.13 | 2.464 | 0.027* |
| Completion time of Task E | 24.87 ± 16.90 | 15.67 ± 6.95 | 9.2 | 3.03 | 0.009** |

$^{*}P < 0.05$, $^{**}P < 0.01$.



participants with different demographic characteristics will be considered.

## Author Disclosure Statement

No competing financial interests exist.

## Funding Information

This work was supported by the Shanghai Planning Office of Philosophy and Social Science (Grant No. 2022BSH001) and the Ministry of Education in China Humanities and Social Sciences (project 23YJA760006).

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