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DESIGN OF RESPONSE CHANNELS TO AUGMENT SPEECH AND LANGUAGE REHABILITATION IN CHILDREN WITH HEARING IMPAIRMENT

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ABSTRACT

Hearing impairment impedes the normal development of speech and language skills in children. Lack of auditory stimulation restricts the ability of children to communicate using spoken language. Consequently, this hinders educational, social and career choices for children as they grow up. The standard of care for children with hearing impairment involves providing appropriate amplification devices (external/implanted) followed by speech and language therapy. The process of therapy is time and labor-intensive for all stakeholders. Regular compliance to therapy requires considerable time commitment by the parent/caretaker, which further implies a cost burden pertaining to therapy sessions and/or loss of wages. These challenges are compounded by the dearth, and a skewed distribution of qualified speech therapists in resource-constrained settings. An affordable intervention was proposed in our earlier work, wherein a smartphone application could facilitate home-based therapy for children with hearing impairment. Further discussions with stakeholders led to identification of other drawbacks in the current system of rehabilitation including lack of means to monitor and track the child's progress during home-therapy. In this work, we propose the use of response channels to serve as quantitative metrics in analyzing and quantifying a child's progress during the process of therapy. This technology-based solution may strengthen the support framework available for parents/caregivers to provide home-based therapy on a regular basis, and possibly reduce the need for frequent visits to the institution.

Keywords: hearing rehabilitation, speech and language therapy, reinforcement

1. INTRODUCTION

The rehabilitation ecosystem for a child with hearing impairment involves multiple stakeholders, including otolaryngologists, audiologists, speech/language therapists and most importantly parents/caretakers of these children. It is commonly accepted that for language to develop, the child must feel the need to express, and there must be an empathetic listener [1][2]. Such a conducive environment for the child requires effective coordination between said stakeholders [3] [4]. The involvement of otolaryngologists and audiologists is limited to diagnosis and fitment of the amplification device, whereas parents and speech therapists are drivers of the rehabilitation process which typically takes 3 - 5 years. This process involves multiple levels of auditory training and is demanding for parents, who are only supported by speech therapists [5][6]. Appropriate speech and language skills develop subject to the child's age when therapy began, and the level of residual hearing [7]. In current settings, speech therapists proceed progressively with training activities based on a tedious and subjective evaluation of the child's progress across sessions. Parents are expected to emulate these activities at home [8][9]

In our previous work [10], clinical immersion and interactions with stakeholders led to identification of unmet needs within the rehabilitation process. The primary challenge was found to be the lack of awareness among parents about the entire

rehabilitation process, particularly during the initial stages [8]. Parents were expected to quickly grasp and execute their additional responsibilities without much added support. A structured framework for parents to deliver therapy at home via smartphones was proposed to address some of these unmet needs, particularly in resource constrained settings [11].

Additional pains and gains were subsequently identified within the hearing rehabilitation ecosystem. Pains are defined as negative emotions, undesired costs, or situations, and risks the stakeholder (could) experience before, during, or after getting a task done. Gains on the other hand are benefits the stakeholder expects, desires or would be surprised by. This includes functional utility, social gains, positive emotions, cost savings, etc. [12]. Pains (P) and gains (G) which were not addressed via the said smartphone application are listed below:

- **P1:** Parents do not provide sufficient feedback about the progress of home-based therapy sessions.
- **P2:** The child has a limited attention span during therapy sessions.
- **P3:** Signs of progress/ improvements \are not clearly visible to parents.
- **P4:** Voice exercises for in-person sessions are straining.
- **G1:** Parents prefer regular one-on discussions with therapists.
- **G2:** Train the child with a wide variety of auditory stimuli.
- **G3**: Increase effectiveness of in-person therapy sessions.

In this paper, we propose a technological intervention to address these pains and gains by extending the scope of the previously developed smartphone application. It is a set of response channels designed to track the child's responses during the course of rehabilitation activities. These channels take the form of buttons, toys, and other items within a child's play environment. The use of this response channel serves as a quantitative metric in analyzing and quantifying a child's progress through the course of therapy. The child's interaction with these triggers' responses, which are then logged by the application for further evaluation and analysis.

2. DESIGN AND DEVELOPMENT

2.1. Prior art study

A prior art study identified certain technological solutions available within the broad domain of speech and language rehabilitation. These were limited to stand-alone smartphone applications that do not cater to and are unaffordable for the Indian context [13].

2.2. Understanding the current settings

Each level of speech and language therapy targets development of a different auditory/language skill. Therapists design different activities to target development of these skills. Consequently, observation of therapy sessions was undertaken as a first step to understand how such activities are designed and conducted by therapists. Prior to this, authorization from the officer-in-charge of the therapy center, and oral consent from the respective parent(s) was obtained. Observations were carried out from an adjoining room via a viewing window to not disturb conduct of the session.

Based on observations and subsequent discussions with therapists, it was inferred that activities are designed to be interactive, with consideration for a child's age, cognitive, motor skills among other items. A session kit consisting of different toys, noisemakers is utilized across activities. A typical kit is shown in Figure 1. Subject to the auditory skill being targeted in the activity, therapists may use one of these toys to generate sounds and engage the child, while correlating if necessary, the shape/form/size etc. of the toy to the sound generated. This approach of leveraging toys for learning is referred to as the 'play-way' method.

Stimulations provided by the therapist, as stated, are expected to generate certain responses from the child. The form of these responses is strongly dependent on the child's age and cognitive

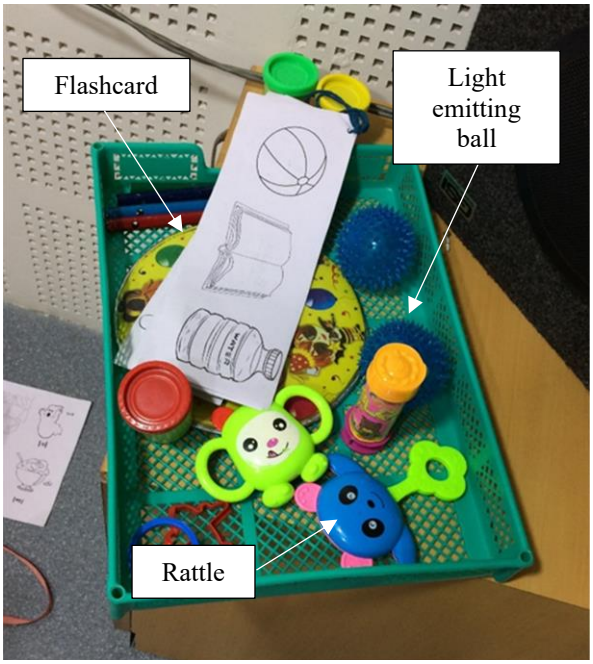

FIGURE 1: A TYPICAL SESSION KIT USED BY SPEECH THERAPISTS

capabilities. This can take myriad forms such as a startled response, smiling, blinking, body movements for babies (up to 2 years of age), and verbal responses, child-specific actions for toddlers (2 years of age and above) [14].

Therapists and parents constantly look for such responses to auditory stimuli during activities. Once a response is identified, a positive reinforcement must be provided by them to the child as a means of encouragement. This can also take myriad forms such as clapping, expressing excitement, playing with a toy, among others.

These set of activities, wherein the child is trained to identify and respond to specific sounds, are collectively referred to as 'conditioned play response.' It is the first step, and a part of the 'sound awareness' level within the overall rehabilitation process [14]. Sound samples presented to the child at this stage must be broad in scope and tailored to account for the typical auditory environment of the child. These usually include animal, traffic sounds, 'ling' sounds, among others.

2.3. System design

This approach of therapists for 'conditioned paly response' activities was abstracted to three key actions: generating auditory stimuli, observing responses, and providing a positive reinforcement. This abstraction was used as a rubric to generate concepts that allow for tracking and evaluation of a child's progress.

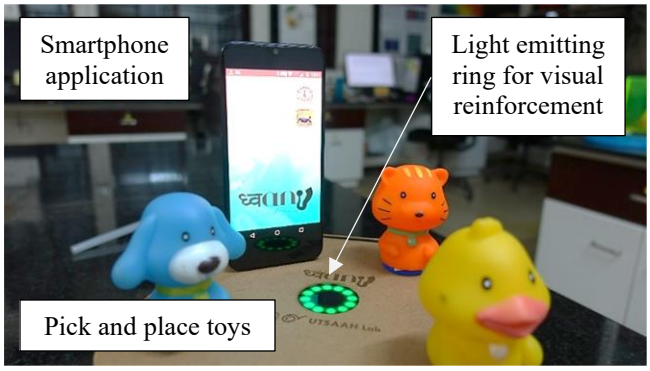

FIGURE 2: DEVELOPED CONCEPT OF THE RESPONSE SYSTEM

The developed concept is a platform on which toys of different form/type/size can be placed. It has a speaker embedded within and connects wirelessly to the smartphone application designed for the Android platform. A light emitting ring capable of producing assorted colors, patterns is placed at the center of the platform. A picture of the prototype is shown in Figure 2.

Inside the platform a radio-frequency identification (RFID) module is used to identify items placed on it (RC522). The toys in turn, have the corresponding RFID tags placed below them. When an auditory stimulus is generated within the smartphone application, it is played back on the embedded speaker. The child is expected to pick/place a toy corresponding to the stimulus. When this is done correctly, different light patterns are generated in the central ring as reinforcement. Simultaneously, this is logged in the application for subsequent analysis. This automated logging is only done for a specific time interval, post which a separate assessment sheet is displayed in the application after each activity wherein the parent has an option to manually record the child's response. Doing so allows the parent to record responses even if they are of a different form (smiling/blinking etc.). The questions also capture parameters such as the response quality, speed, type etc., for subsequent subjective analysis. The application has an extensive repository of auditory stimuli,

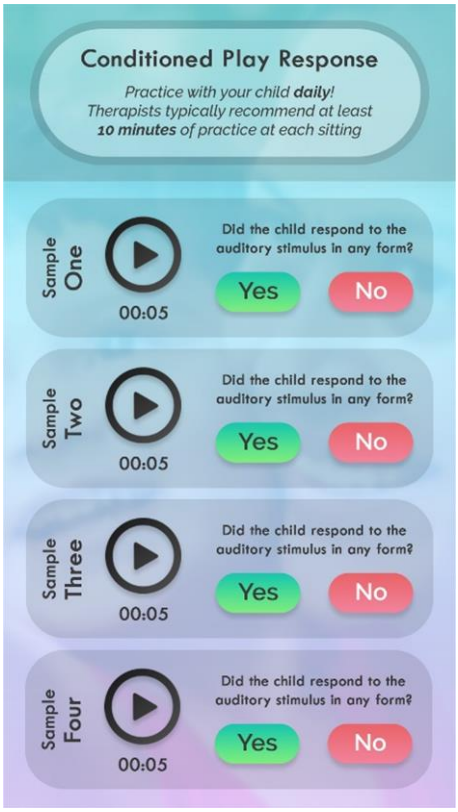

FIGURE 3: APPLICATION USER INTERFACE WHEN AN ACTIVITY IS BEING CONDUCTED

which can be tailored to a specific child and auditory context. The screen of the application when an activity is being conducted is shown in Figure 3.

The system is agnostic to the type of toy used. Modular tags allow the parent to couple it with a wide variety of toys to enable context specific learning. Sound samples currently within the application are limited to 'conditioned play response' activities within the 'sound awareness' level.

The concept builds on the benefits of the 'play-way' method to improve the child's attention span. Adoption of the stated workflow should allow objective assessment of a child's progress within the activity and across the rehabilitation process.

3. EVALUATION METHODOLOGY

The evaluation of the prototype device and its overarching concept was guided by the minimum viable product (MVP) testing protocol of the lean startup approach [15].

Pain relievers (PR) and gain creators (GC) were hypothesized based on the pains and gains stated earlier (Section 1), and prior discussions with stakeholders. Pain relievers describe exactly how a product or service alleviates stakeholder pains. Gain creators on the other hand describe how a product or service creates stakeholder gains and how it offers added value to the stakeholder. [12][15]. These are listed in Table 1 with

corresponding pains and gains. Parents who have successfully completed the rehabilitation process with their child and speech therapists were chosen to evaluate the device. This was done to ensure maximum feedback is received and incorporated prior to a rigorous, long drawn clinical investigation with parents undergoing therapy. Interviews were conducted with individuals in each category, prior approval for which was obtained from the institute human ethics committee (application number: IEC/1/495 12020). The overall concept was explained to the interviewee, followed by demonstration of the prototype. No child was involved in the evaluation process. Neutral, non-leading questions were asked to probe for each PR, GC. These are listed in Table A1, within the Appendix of the paper. A Likert scale- based evaluation was then employed to quantify responses. This was followed by specific questions pertaining to the design of the current prototype, which were framed to provide feedback and serve as an input for subsequent versions. Each interview took an average of one hour, and a total of 8 individuals (4 parents, 4 speech therapists/audiologists) were covered. The overall evaluation process is summarized in Figure 4.

4. RESULTS AND DISCUSSIONS

Each PR, GC was rated by respondents on a 5-point Likert scale

P/G	PR/GC	DESCRIPTION
P1	PR1	Mechanism for therapists to monitor/ track home- based therapy delivery by parents
P2	PR2	Methods/activities that increase the attention span of the child
P3	PR3	Objective tracking and analysis to quantify the child's progress over the course of therapy
P4	PR4	Availability of a wide variety of pre-recorded sound samples for use during therapy sessions
G1	GC1	A platform for parents to report progress to, and coordinate with speech therapists
G2	GC2	A sound sample repository for training the child, which can be tailored to a specific auditory context
G3	GC3	Provide various tools and design activities to improve the speech therapy (Gamified approach)

TABLE 1: PAIN RELIEVERS, GAIN CREATORS FORMULATED FOR EVALUATION OF THE CONCEPT

(Strongly Agreed, Agreed, Neutral, Disagreed, Strongly Disagreed). These results are listed in Figure 5. Results of the design evaluation and any other comments/insights not falling into these buckets were listed separately. These results are presented in Table 3 and 4.

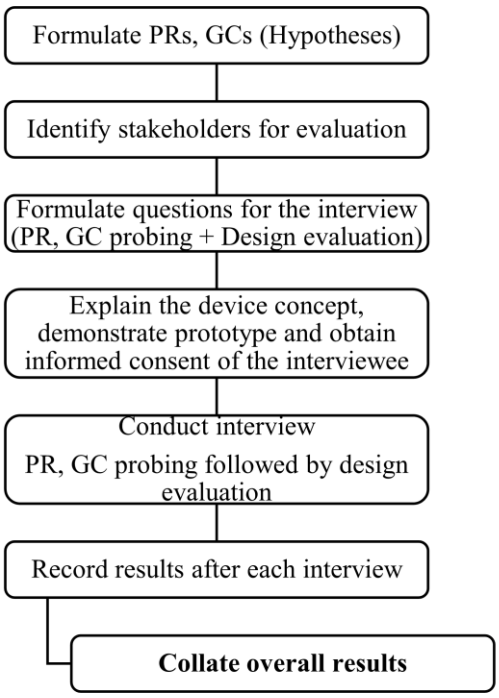

FIGURE 4: PROCESS ADOPTED FOR EVALUATING THE CONCEPT

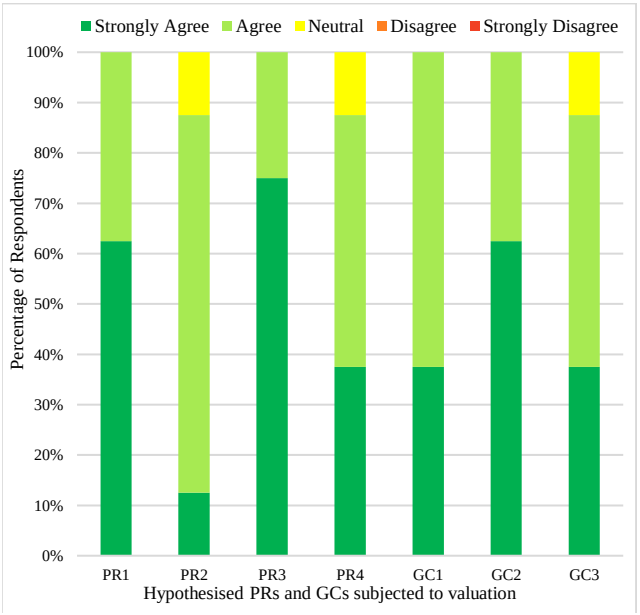

FIGURE 5: SUMMARY OF EVALUATION OF PAIN RELIEVERS AND GAIN CREATORS

Each hypothesis was validated to a varying degree. During interviews additional gain creators for the system emerged which had not been anticipated earlier. As an example, parents anticipated that the use of different prerecorded sounds for

#	SUMMARY OF RESPONSES TO DESIGN EVALUATION
1	What impact do you see when direct reinforcement is provided to the child during the activity?
Interviewees underscored the importance of providing the child with immediate and direct reinforcement upon successful completion of an activity. It was also anticipated that this would motivate children to take up successive activities in a competitive manner. With regards to the current prototype device, it was pointed out that the toy would be more appealing to the child than the light emitting ring.	
2	How many times should we undertake an activity (with reinforcement) before moving on to the next one?
A definite answer to this question did not emerge across interviews. It was found that the number of attempts required depends on myriad factors like age of the child, cognition, degree of hearing impairment, among others. An alternate, and important parameter to track would be whether a child has successfully completed an activity.	
3	What are your views on the modality for the response system (pick/place etc.)? In your view, what other modalities are required for the response system?
A pick/place modality was found to be suitable for the initial stages of the process in addition to pointing at objects. With regards to additional modalities, interviewees spoke about the need to encourage vocalizations in subsequent stages of the process.	
4	What would you prefer: A response system kit with multiple toys or a single toy with multiple modalities of interaction?
A definite answer to this question did not emerge across interviews. The authors however noticed that each interviewees answer was guided by an underlying concern about affordability.	
5	In your view, what parameters of the sound playback should we control (volume, etc.)?
Volume was found to be the most important parameter to control when playing back recorded sounds to a hearing-impaired child. Additionally, it was pointed out that the child must be exposed to a wide variety of human sounds as well.	
6	How do you think the data and responses captured from the response system could be utilized?
Two primary uses were pointed out: objective metrics for evaluating progress of a child and guidance criteria for parents to determine when to move on to the next activity during home-based therapy.	

TABLE 3: COLLATED RESULTS OF DESIGN EVALUATION

training at an early age would help these children better generalize the concept of sound instead being accustomed to something specific. With regards to the design evaluation, certain questions did not yield clear answers since these were found to be dependent on the specific child. This warrants that subsequent versions be made modular and adaptable. Privacy issues with regards to the data captured could also arise, which must be appropriately addressed as the system evolves.

#	OTHER INSIGHTS
1	The overall system abstraction of stimulation-observation-reinforcement could be extended to assist in training activities for children with other conditions such as autism.
2	The system is relevant in the current context in view of the disruptions caused by the COVID-19 pandemic. While remote education has been made possible by multiple tools, there are limited, if any, tools for assisting remote delivery of therapy
3	Interviewees pointed out that the system can also help family members undertake therapy at home, allowing the parent to share their workload
4	While the use of a smartphone application was welcomed, interviewees, particularly parents highlighted the need to control and minimize screen time required of children during conduct of therapy activities

TABLE 4: OTHER INSIGHTS OFFERED BY STAKEHOLDERS DURING THE INTERVIEW

5. CONCLUSION & FUTURE WORK

In this paper we propose a system to monitor and track the child's responses during therapy sessions. The system objective assessment of a child's progress through therapy and enables therapists to make targeted course corrections. An evaluation approach guided by the minimum viable product (MVP) testing protocol of the lean startup approach was adopted followed by a Likert scale evaluation. The prototype device and its overarching concept were found to be meeting their stated goals.

The system was found to be suitable for the targeted ecosystem based on a preliminary survey of healthcare providers and experienced parents in this domain. Further development of the system based on feedback received from the evaluators and a rigorous clinical study to gauge efficacy of the system is planned as future work.

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APPENDIX

#	QUESTION
PR, GC probing	
1	Based on your prior experience, what is your opinion about the response system?
2	How does the developed scoring mechanism compare to your current method of tracking the child's progress?
3	What do you think about the device being used for activities pertaining to sound awareness?
4	Which mode of reinforcement would be more appealing to the child (visual, sound, motion)?
5	How do you see this device being used by parents to deliver therapy at home?
6	Do you feel the response system is suitable for use by a child (robust/compact etc.)?
7	How do you see this device being used to conduct therapy sessions at your center?
8	Can this response system be used in other levels of therapy?
9	Do you have any other feedback for the response system in particular?

TABLE A1: A TYPICAL SESSION KIT USED BY SPEECH THERAPISTS

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