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Acceptability of a home-based humanoid robot for deaf children with cochlear implants and their family: A first step towards a remote speech-language training tool

Sabrina Stiti^{1,2}, Loïc Caroux², Pascal Gaillard², Pierre-Vincent Paubel², Pascal Barone¹ & Olivier Deguine^{1,3}

Abstract— This study explores the acceptability of a humanoid robot in the homes of deaf children with cochlear implants. Traditional audiologic rehabilitation, usually conducted at hospitals or clinics, significantly improves communication but geographical distance and parental availability pose challenges for families. Introducing home training with a humanoid robot could provide greater equity in care distribution, aid in the child's progress, and offer an ecological approach. Here, ten families (11 cochlear-implanted (CI) children aged 7–12 years and their parents) participated in a study evaluating the acceptability of the humanoid robot (called Pepper) in their homes for one month. We identified two distinct clusters among the 11 CI children. The first cluster ("younger CI Children") demonstrated better and higher scores for acceptability, usability, usefulness, emotion, and fun, and used the robot more than children in the second cluster ("older CI children"). We found a decrease in both duration of use and number of applications launched by CI children each week when interacting with the robot. Parents showed similar results to their children, with parents of younger CI children demonstrating greater acceptance of the robot. Various technical issues (transcription errors, robot non-responsiveness, and comprehension difficulties) may have affected the robot's acceptability among both CI children and their parents. Both CI children and parents expected humanoid robots to have more advanced capabilities, including high social intelligence, advanced artificial intelligence, voice assistant features, and Natural Language Processing integration.

I. INTRODUCTION

Effectiveness of audiologic rehabilitation for cochlear-implanted (CI) children, conducted through pluri-weekly sessions in hospitals (Ear, Nose, and Throat (ENT) services) or clinics (with speech therapists), significantly improves the communication abilities of CI children. However, access to this care can be challenging for patients and families [1]. Implementing home training with appropriate tools could help address this issue by ensuring more equity in the distribution of care and facilitating the child's progress [2]. Introducing a humanoid robot for complementary training could also provide an ecological approach to this endeavor.

Before proceeding with a home-based complementary speech-language training with a social robot, it is crucial to investigate the acceptability of the humanoid robot at home.

This is both from the perspective of CI children and their families. In fact, this study was driven by the consistent report of research findings highlighting the shortage of access to hearing care professionals for families due to medical desertification [1]. We implemented a novel research methodology framework recently designed and published by Stiti et al. [3] for the evaluation of the acceptability of a social robot at home for deaf children with cochlear implants. Additionally, this method considers the acceptability of the robot by family members during a 1-month stay, a factor not yet addressed in prior research.

Our primary research questions were as follows: 1) How can we determine if the humanoid robot can be used for remote training at home with CI children and their parents, and whether they would accept the robot in their home for a month? 2) What factors of CI children may influence their perceived interaction with the humanoid robot? To address these questions, we conducted an exploratory study for 1 month on 11 CI children aged 7 to 12 years and their parents with a humanoid robot called "Pepper" at home.

Our article begins with an overview of the use of socially-assistive robots in healthcare for individuals with special needs, especially CI children, and the acceptability of a social robot. Then, we elaborate on the methods and procedures of the study conducted. Finally, we describe our results followed by a discussion of the findings and future research perspectives.

II. STATE OF THE ART

A. The use of Socially Assistive Robots in healthcare for people with special needs

A Socially Assistive Robot (SAR) is a type of robot designed to interact with humans in a socially and emotionally supportive way [4]. Unlike many other types of robots that perform physical tasks or automate processes, SARs primarily focus on providing social and emotional support, especially in healthcare, education, and therapy. These robots are programmed to engage in social interactions, monitor human behavior, and respond to the emotional and social needs of an individual [5]. Additionally, they perform tasks according to personal preferences and answer questions by

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connecting to a database [5]. In the healthcare field, SARs are used in the care of the elderly, children, and individuals with disabilities [6]. In this context, these robots can provide solutions to shortages in hospitals, nursing homes, rehabilitation centers, and associations. This impact extends beyond the elderly and their families to include healthcare workers themselves and individuals with special needs, as well as anyone requiring physical or mental care [6]. Social robots can be valuable aids in caring for the elderly, improving their well-being, quality of life, and health, while also reducing feelings of depression and loneliness [7]. They have also been linked to benefits such as cognitive stimulation, enhanced blood pressure, and the alleviation of pain in elderly individuals during the administration of painful treatments, while at the same time reducing the workload of caregivers [8]. SARs can benefit children with special needs [9]. Indeed, a SAR can also help a child with autism spectrum disorder (ASD) with social communication skills and enhance interactions. For children with physical disabilities, SARs have shown to improve motivation, attention, initiative, and concentration during cognitive and physical rehabilitation. In addition, children with cerebral palsy having utilized a SAR have experienced benefits not only in cognitive growth and learning, but also in enhanced communication, motor skills, emotional expression, and visual regard (engagement) [9]. SARs have also been used to target the mental health of children with cancer [9] and research has been conducted with a specific focus on children with hearing impairments, aiming to demonstrate the advantages of SARs in their rehabilitation. Notably, there is a scarcity of studies involving SARs among deaf children with cochlear implants. In general, SARs have been extensively employed for individuals with special needs. However, the majority of these studies were conducted over a short time period with no follow-up (representing 69% of studies in healthcare with children [9]). In addition, the number of subjects were small, due to the specificity of the population under study, and the studies lacked reports on any ecological measures.

B. Benefits of SARs for deaf children with cochlear implants

Cochlear implantation is acknowledged worldwide as a secure and dependable treatment for children with severe to profound hearing loss. The principal advantage of this medical intervention in children lies in the restoration of their hearing, with the anticipation that this improved auditory ability would enhance their communication [10]. After implantation, factors such as age, medical conditions, social factors, and bilateral hearing affect speech development. Early implantation is crucial for maximum benefit, and targeted therapy is essential for language development. While restoration of bilateral hearing by early cochlear implantation does enhance the benefits of communication, on the other hand social factors and medical complexities (i.e. comorbidities, surgical complications etc.) can limit these overall benefits [10]. Children with hearing impairment are at an increased risk of language, academic, and social difficulties [11]. Assessing the speech perception and intelligibility of young deaf children requires specialized tests

and long-term monitoring following cochlear implantation [12]. Cochlear implantation outcomes in children vary due to individual and family factors, and global disparities in implant program availability present significant challenges [1]. Although children view SARs as friendly, helpful, and entertaining, [13] SAR development for use with children remains relatively unprogressive. This is due to a lack of technological capabilities and societal acceptance [5]. In a study by Ioannou and Andrevia [13], hearing-impaired children using hearing aids or cochlear implants were involved to investigate the effectiveness of NAO, a small humanoid robot. NAO was designed to interact with humans and has various capabilities in speech recognition, object recognition, and basic communication skills, with also activities for speech therapy. The key advantage of NAO over traditional speech therapy sessions was its ability to create an engaging and enjoyable learning environment. The study showed children improved steadily over the six-week intervention, especially in the final two weeks, becoming more responsive to sounds. The children also showed positive attitudes towards the robot and enjoyed the sessions, suggesting social robots could enhance learning and provide personalized instructions in education. Uler et al. [14] explored the use of a humanoid robot equipped with emotion recognition to support children with hearing loss during auditory testing. The study examined three different setups: a conventional setup with audiologists, a tablet-based setup with auditory games and visual feedback, and a robot plus tablet setup with feedback conveyed through robot gestures. Researchers concluded that children accepted the robot as a clever and enjoyable social presence [14]. Although test scores did not significantly differ from traditional auditory-verbal therapy methods, the digital environment (robot plus tablet) increased motivation and engagement. For researchers, this promising development serves as an encouraging initial stride toward integrating these emotionally responsive robots into audiologic testing [14].

Acceptability in the context of social robots refers to the extent to which individuals find their use in daily life appropriate, desirable, and beneficial. While the assessment of SAR acceptability in healthcare is well known for various populations, including the elderly people [15] and among those with ASD [16], there is currently no prior research findings on the assessment of acceptability among CI children and their families.

III. AIM OF THE STUDY

Overall, research on SAR acceptability in healthcare is established for various populations but lacks focus on CI children and their families. CI children often face challenges with traditional rehabilitation methods, but home-based training with a humanoid robot could offer more accessible and effective care. The primary questions of this study therefore focused on whether the humanoid home-based robot Pepper could be perceived as acceptable over time and whether the perceived acceptability remained stable over time. An exploratory study with 11 CI children aged 7 to 12 years and their parents was conducted over 1 month. We used the innovative protocol from Stiti et al. [3]. The complete

procedure and questionnaire details can be found in Stiti et al.[3].

IV. METHODS

A. Social robot

The humanoid robot "Pepper" (SoftBank Robotics, 2014) was chosen for this study (see Stiti et al.[3] for details of the robot implementation). The robot can speak and hear and performs facial and voice identification. The speech rate was set to 80 words per minute (wpm) and could be adjusted by the researcher or by the child using a tablet or asking the robot to change the volume. Sound settings were also customized at home with the child. It has a touch pad on its chest and offers activities such as playing, dancing, and conversing (personalized discussions on the child's interests, storytelling). Specifically, games and activities were developed for this study and personalized for CI children. These games aimed to enhance language skills while being appropriately challenging but not too difficult to solve (e.g. memory game, guess the animal, hangman game, dance choreography and imitation dance). For instance, questions were programmed into the robot based on the child's areas of interest, with five thematic categories each containing 10 questions (see Stiti et al. [3] for examples). These questions could only be activated through vocal commands.

B. Populations

A total of 11 children with cochlear implants (6 girls and 5 boys) and 10 parents (questionnaires were completed by one parent in each family) participated in the study. Family number 8 had 2 children with cochlear implants, referred to as children numbers 8 and 9. CI children had a mean age of 10.1 years ($SD = 1.5$) and were implanted at a mean age of 2.3 years ($SD = 1.7$), had a mean lexical age of 9.4 years ($SD = 3.9$), and a mean Categories of Auditory Performance (CAP) score of 5.9 ($SD = 1.0$). Parents had a mean age of 45.4 years ($SD = 6.8$), primarily lived in houses, except for one family in an apartment.

All ten families had a favorable family environment and high involvement in the child's rehabilitation, with an mean score of 4.9 out of 5 on the Early Family Participation Scale [17]. All subjects completed the study procedures except for child number 1 and their family; they no longer participated after day 23 due to a major technical issue with the robot, leading to a poor user experience. The family still opted to discontinue their study participation despite the technical problem being resolved.

C. Ethics statement

All participants gave their written informed consent to take part in this study. This research was approved by the Ethics Committee for Human Research in Ile de France Region 1 N°IRB: IORG0009918 (Paris, France), study number: 21.03768.041844-MS02. The promoter is the Toulouse University Hospital: RC31/20-0250. Clinical Trials ID: NCT04832373; <https://clinicaltrials.gov/>

D. Procedure

The study took place in several stages. We used the methodology from Stiti et al.[3]. Details of the procedure can be found in this article. The study began with pre-inclusion. Here, the ENT department in the pediatric cochlear implantation unit (UPIC) introduced the study, assessed eligibility, and explained the study purpose. Upon inclusion, both parents and children signed consent forms. Participants completed an initial questionnaire covering demographic information and technology usage [18]. After, the robot was installed in their homes for a period of 30 days. Four weekly visits ensured smooth operation, the collection of data on interactions with the robot (time of use and number of applications launched), CI children questionnaires (usability: adapted System Usability Scale (SUS), usefulness: meCue Module 1, emotion: meCue Module 2 and fun: Funometre) and drawings. This "drawing intervention" allowed children to express their experience with the robot through drawings, without spoken or written words. We also collected parent questionnaires (acceptance (the Almere Model), attitude toward using a robot (Use Intention Scale), behavioral intention to use a robot (Use Intention Scale)), and gathered family observations. The study concluded with the removal of the robot and completion of final evaluation questionnaires. The detailed protocol and references are available from Stiti et al. [3].

V. DATA ANALYSIS

Acceptability was assessed based on objective (e.g. time of use, number of applications launched on the robot) and subjective measures of usability, intention to use, and fun. The change in these measures over time and the mean scores were analyzed by a linear mixed model. The objective of the analysis was to identify distinct user profiles based on their acceptability of the robot, ranging from those who highly accepted the robot to those with a low level of acceptability. The resulting user profiles identified will provide valuable insights for selecting families in future stages of our research, specifically for the implementation of a home-based humanoid robot as a remote speech-language training tool.

The exploratory outcomes addressed in the present study were the following:

ERQ1: Can we identify clusters to classify the children in our cohort into subgroups based on their perceptions of their interactions with the robot?

ERQ2: What are the variables in our dataset that play pivotal role in distinguishing CI children into different clusters?

ERQ3: How does the data from the children and their parents change over the 1-month stay at home (questionnaires and robot-generated data)?

ERQ4: Does the age of CI children influence their perceived interaction with the humanoid robot Pepper, and how?

A. Statistical analysis

The data were analyzed using the statistical program R Studio. Data were not normally distributed, so we adopted non-parametric statistical tests (e.g. linear mixed model).

Descriptive statistics were first conducted to describe the demographic characteristics of the subjects. A cluster analysis and a principal component analysis (PCA) were used to examine the data set in terms of the research questions (ERQ1, ERQ2, ERQ4). The analysis of objective variables (time of use, number of applications launched) excluded child number 3 due to an error in the transcription of activities over the entire month. Children 4 and 5 also experienced transcription errors on some days, which were addressed by substituting written records made by the children concerned. Consequently, we conducted the analysis of objective variables (time of use, number of applications launched) with the exclusion of children 3, 4, and 5. Analysis of variables were based on two factors: "Cluster" (Cluster 1: "older CI children" and Cluster 2 "younger CI children") and "week" (4 weeks of the robot's stay). We also developed feedback and general observations of CI children and their parents.

VI. RESULTS

A. Identification of Clusters among Children with cochlear implants

We performed a K-means clustering [19] and a PCA analysis to identify two distinct groups (Elbow method) among the 11 CI children based on their interaction with the humanoid robot at home. The analysis focused on four variables: "fun," "usability," "usefulness," and "emotion." Through K-means clustering, the children were divided into two clusters: Cluster 1 ("older CI children"), with lower scores for interaction, and Cluster 2 ("younger CI children"), with higher scores for interaction (See Table I). The PCA analysis revealed that "fun" and "usability" were key dimensions differentiating the clusters, explaining 93.5% of the variance (fun: 80.4%, and usability: 13.1%).

TABLE I. REPARTITION OF CI CHILDREN BY CLUSTER

Number of Cluster	CI Children		
	Name of cluster	Mean age (years old)	Children number
1	Older children	11	1,2,4,8 and 10
2	Younger children	9,33	3,5,6,7,9 and 11

B. Exploring the effects of cluster and week number with the robot on robot acceptability by CI children

A linear mixed model was applied to estimate the mean change in the number of weekly hours of robot use over time across the entire study population (objective variables). This same analytical approach was employed for the results obtained from repeated measurements of questionnaires administered during the follow-up, focusing on factors such as usability, acceptability, enjoyment, and emotional responses (subjective variables).

Objective variable: Number of applications launched: Children from the "older CI children" cluster tended to generally launch less applications than children from the "younger CI children" cluster ($\chi^2 = 2.986$, $df = 1$, $p = 0.083$). CI children launched less applications on the robot each week ($\chi^2 = 23.663$, $df = 3$, $p < .001$), highlighting the influence of the duration of the robot's stay on the number of applications launched. This implied that the impact of the weeks of the robot's stay ("timing") on the "number of applications launched" by CI children varied across clusters and the duration of the robot's stay, with a decrease in the number of applications launched each week of stay. The interaction effect revealed a decrease in the number of applications launched over the weeks for "older CI children". Specifically, there was a decreasing trend between week 1 and week 2 with a coefficient estimate of 51.75 (SE = 19.15, $t = 2.702$, $p = 0.064$). Additionally, a significant decrease was observed between week 1 and week 3, with a coefficient estimate of 62.75 (SE = 19.15, $t = 3.276$, $p = 0.020$), and between week 1

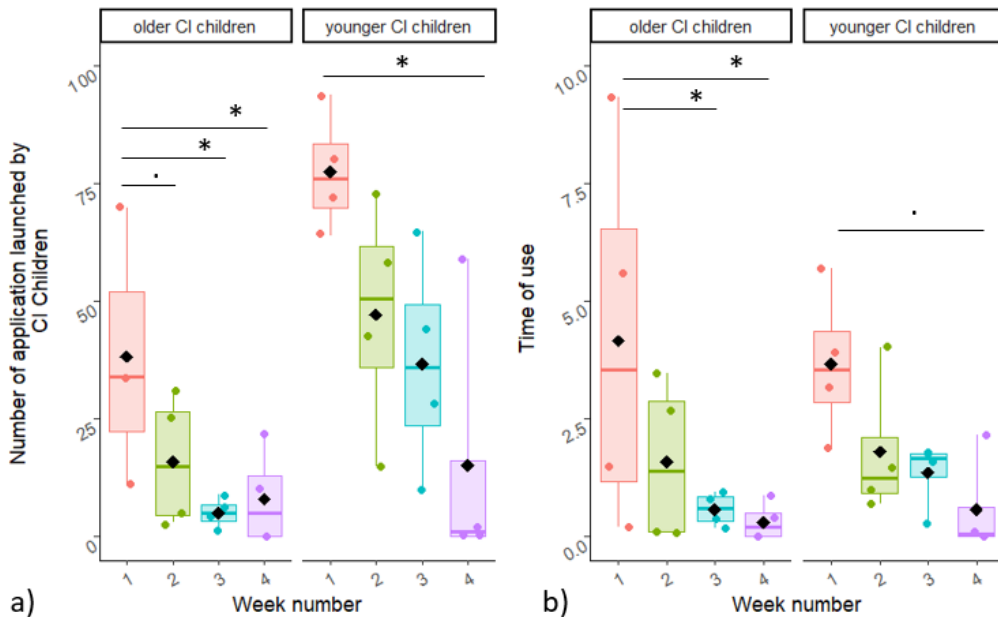


Figure 1. CI children objective variable a) Number of applications launched by CI children by cluster and timing; b) Time of use of the robot (in hours) by cluster and week of stay.

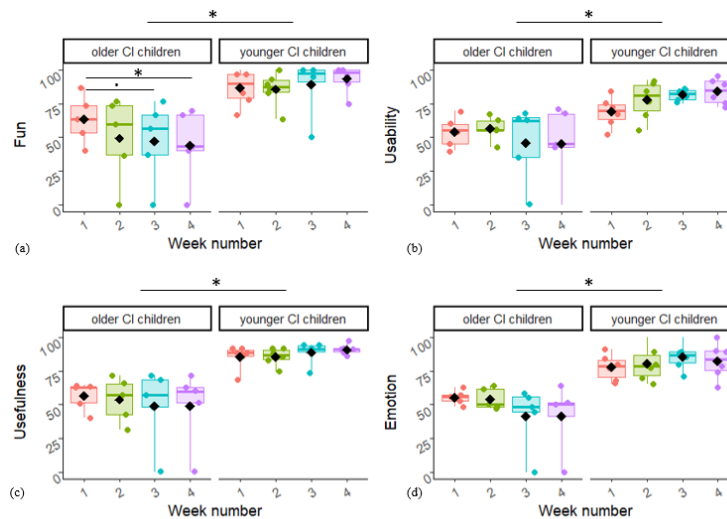


Figure 2. CI children subjective variable: (a) fun score, (b) usability score, (c) usefulness score, (d) emotion by cluster and week of stay.

and week 4 with a coefficient estimate of 59.75 (SE = 19.15, $t = 3.120$, $p = 0.027$). For "younger CI children", the interaction effect revealed a significant decrease in applications launched between week 1 and week 4 with a coefficient estimate of 62.25 (SE = 19.15, $t = 3.250$, $p = 0.021$; see "Fig. 1a. ").

Objective variable: Time of use: CI children spent less time with the robot each week ($\chi^2 = 19.669$, $df = 3$, $p = 0.0001$). There were no significant differences between the clusters ($\chi^2 = 0.057$, $df = 1$, $p = 0.810$). "Older CI children" had a significant decrease in time of use between week 1 and week 3 with a coefficient estimate of 0.148 (SE = 0.049, $t = 2.997$, $p = 0.035$), and a significant decrease was found between week 1 and week 4 with a coefficient estimate of 0.160 (SE = 0.049, $t = 3.220$, $p = 0.022$). "Younger CI children" had a decreasing trend between week 1 and week 4 with a coefficient estimate of 0.129 (SE = 0.049, $t = 2.598$, $p = 0.078$; see "Fig. 1b. ").

Subjective variable: Fun score: "Younger CI children" had significantly more fun than "older CI children" during the month of robot stay at home ($\chi^2 = 10.138$, $df = 1$, $p = 0.001$; see "Fig. 2a. "). For CI children, there were no differences in mean fun score between each week ($\chi^2 = 3.712$, $df = 3$, $p = 0.294$). The interaction between "cluster" and "week" had a significant impact on the response variable "fun" ($\chi^2 = 11.378$, $df = 3$, $p = 0.009$). Fun score for "older CI children" significantly decreased between week 1 and week 4 with a coefficient estimate of 19.340 (SE = 5.855, $t = 3.303$, $p = 0.0136$), and a decreasing trend was found between week 1 and week 3 with a coefficient estimate of 15.993 (SE = 5.855, $t = 2.732$, $p = 0.050$). On the contrary, fun score for "younger CI children" showed no significant differences between each week. Hence, "older CI children" experienced a decrease in perceived fun with the robot between week 1 and week 4, while "younger CI children" consistently enjoyed a high level of fun with the robot over the one-month.

Subjective variable: Usability: "Younger CI children" had a significantly higher mean usability score than "older CI children" over the month of robot stay at home ($\chi^2 = 15.900$, $df = 1$, $p < .001$; see "Fig. 2b. "). For CI children, there were

no differences in mean usability score between each week ($\chi^2 = 1.117$, $df = 3$, $p = 0.772$). Concerning the interaction between CI children in "cluster" and "week", there were no significant differences in mean "usability" score between each week ($\chi^2 = 5.913$, $df = 3$, $p = 0.115$). This implied that the week number did not significantly contribute to "usability" across clusters. Thus, "younger CI children" had a better perceived usability of the robot that remained stable throughout the month. This is in contrast to "older CI children" who had a lower usability score, but this also remained stable throughout the one-month study period.

Subjective variable: Usefulness: "Younger CI children" had a significantly higher mean usefulness score than "older CI children" during the month of robot stay at home ($\chi^2 = 17.210$, $df = 1$, $p < .001$; see "Fig. 2c. "). For CI children, there were no differences in mean usefulness score between each week ($\chi^2 = 0.235$, $df = 3$, $p = 0.971$). The interaction between "cluster" and "timing" had no significant impact on the response variable "usefulness" ($\chi^2 = 4.580$, $df = 3$, $p = 0.205$). This implied that the week number of robot stay did not significantly contribute to usefulness score across clusters. Therefore, over the one-month duration, "younger CI children" consistently perceived the robot as more useful than "older CI children", but both clusters remained stable throughout the one-month study period.

Subjective variable: Emotion: "Younger CI children" had a significantly higher mean positive emotion score than "older CI children" during the month of robot stay at home ($\chi^2 = 28.275$, $df = 1$, $p < .001$; see "Fig. 2d. "). For CI children, there were no difference in mean emotion score between each week ($\chi^2 = 1.030$, $df = 3$, $p = 0.793$). The interaction between "cluster" and "timing" had a notable trend ($\chi^2 = 6.935$, $df = 3$, $p = 0.073$). This implied that emotions remained stable throughout the robot's stay at home for CI children. Additionally, "younger CI children" expressed a more positive emotion toward the robot compared to "older CI children". However, there were no significant differences in level of emotion between each week of stay of the robot for each cluster of CI children.

Drawing Intervention from CI children: Drawing conclusions from the "drawings intervention" task [20] was challenging due to the limited number of responses collected. Some children considered the exercise too "childish" for their age and chose not to complete the task, making it difficult to derive meaningful conclusions. Most of children who did not complete the task were from the "older CI children" cluster.

C. Exploring the effects of cluster and week number with the robot on robot acceptability by the parents

Contrary to the CI children, parents did not complete questionnaires each week, but did for week 1, week 3, and week 4 (week 2 was skipped to lighten the task). A linear mixed model was applied to estimate the average change in robot acceptability over time across parents. This analytical approach was employed for the results obtained from repeated measurements of questionnaires administered during the follow-up, focusing on factors such as acceptance, attitude toward using the robot, and behavioral intention to use the robot. The subsequent analysis was conducted based on the clustering of parents according to their children.

Acceptance score: Parents of "younger CI children" had a trend for a higher level of acceptance than parents of "older CI children" ($\chi^2 = 3.392$, $df = 1$, $p = 0.065$). For parents of CI children, there were significant decreases in mean acceptance score between each week ($\chi^2 = 12.014$, $df = 2$, $p = 0.002$). For parents of "older CI children", the level of acceptance showed a significant decrease between week 3 and week 4 with a coefficient estimate of 13.600 (SE = 4.894, $t = 2.779$, $p = 0.034$). Similarly, the level of acceptance of parents of "younger CI children" demonstrated a decreasing trend between week 1 and week 4 with a coefficient estimate of 12.200 (SE = 4.894, $t = 2.493$, $p = 0.059$).

Attitude toward using a robot: Parents of "younger CI children" had a significantly better "attitude toward using a robot" than parents of "older CI children" ($\chi^2 = 3.951$, $df = 1$, $p = 0.046$). However, the week number had no significant impact on attitude ($\chi^2 = 1.6985$, $df = 2$, $p = 0.427$). Parents from both clusters remained stable throughout the study duration.

Behavioral intention to use a robot: Parents of "younger CI children" had a trend for better "behavioral intention to use a robot" than parents of "older CI children" ($\chi^2 = 3.799$, $df = 1$, $p = 0.051$). Week number did not significantly impact "behavioral intention to use a robot" ($\chi^2 = 1.376$, $df = 2$, $p = 0.502$). The interaction between "cluster" and "timing" had a notable trend ($\chi^2 = 4.910$, $df = 2$, $p = 0.085$), especially for parents of "younger CI children" showing a decreasing trend between week 3 and week 4 with a coefficient estimate of 1.260 (SE = 0.552, $t = 2.282$, $p = 0.087$).

D. CI children and their parents feedback experience and observation with the humanoid robot Pepper at home

During the 1-month stay of the robot at home, 100% of families reported that interactions with the robot were lacking diversity in terms of the applications and conversation. These were the main reasons why children used the robot less each week. Indeed, the families expressed boredom toward the robot's lack of diversity once they had finished testing all the

functionalities proposed by Pepper. Thus, parents suggest that an update of functionalities would have been valuable during the study. The majority of families (90%) stated that they would participate in the study again, but only with an upgraded version of the robot aimed at speech and hearing training (this is except for family 1 that no longer participated in the study due to major robot dysfunction on the 23rd day). Overall, 70% of parents participated actively in the study by being available and curious about each step of the study. These parents were rather receptive to the follow-up and their children using Pepper. The remaining 30% of parents gave their children more freedom with the robot and management of questionnaires. All CI children and their parents praised the personalized themes of conversation and music offered by the robot. During home visits to observe robot-child interactions, we observed two distinct subjective "behavioral profiles": those who were "hyper-excited" and those who were "calm." Interestingly, the "hyper-excited" children tended to be younger compared to the "calm" ones. Approximately 40% of CI children considered themselves too old to engage with the games suggested by the robot. This observation was also echoed by parents. Age-appropriate games will be considered for future studies. Our goal is to develop speech-language training in the form of serious games.

All families highlighted the challenge of communicating with Pepper. It was reported orally and/or added as notes into the questionnaires that having a fluent conversation with Pepper was impossible. As a humanoid robot, Pepper was limited in comprehension and oral expression, a deficiency noted by families who expected more interaction. However, despite the lack of fluent interactions, approximately 63.6% of CI children (all "younger CI children" and 1 child from the "older CI children" cluster) expressed orally during semi-structured interviews that they had taken a liking to Pepper and had got familiar with Pepper's way of talking. Three children even felt sad about having to part with the robot when it left the house at the end of the study.

In terms of study challenges, a substantial amount of technical disabilities with the robot were encountered at the beginning of the study. These had an impact on the interaction of the robot with families (27% of CI children encountered transcription errors). Indeed, all data from the robot were lost due to an error in the robot script for child number 3. Children 4 and 5 also had transcription errors on some days, which were addressed by substituting with written records made by the children concerned.

VII. DISCUSSION

This study investigated the acceptability of a humanoid robot called Pepper for CI children and their parents at home. Regarding ERQ1, we aimed to identify clusters among CI children based on their perceptions of their interactions with the robot. Our findings revealed two distinct clusters. Cluster 1 comprised older CI children, who exhibited lower levels of acceptability, compared to Cluster 2, composed of younger CI children.

For ERQ4, we explored whether the age of CI children influenced their perceived interaction with the humanoid robot. Results revealed that younger CI children had higher

levels of fun, more positive emotions toward the robot, and greater usage of the robot. Additionally, they found the robot more useful compared to older CI children. These results suggest, unlike studies involving children with other specific needs (e.g., ASD, physical disabilities, cerebral palsy) [9], that there could be a distinction based on age within our group of CI children, with indeed older children showing less acceptability. This finding could parallel the understanding that early implantation is crucial for maximizing language and social development benefits, and early deployment of remote speech-language rehabilitation with a humanoid robot is equally required [10].

In addressing ERQ2, we explored the variables that contributed to distinguishing CI children into the different clusters. Our results highlighted the subjective variables "fun" and "usability" as pivotal for differentiating the different clusters. In all, these variables explained 93.5% of the variance, with "fun" alone actually accounted for 80.4% of this variance. Together with the findings from Uluer et al.[14], we find it likely that younger CI children (with the highest level of "fun") would experience greater improvements in their learning compared to older CI children when undergoing a remote speech-language training at home with a SAR.

For ERQ3, we examined the general change in data from the children and their parents over the one-month stay at home (questionnaires and robot-generated data). Results indicated that subjective variables, such as emotion, fun, usability, and usefulness, remained stable over the one-month period. However, objective variables showed a significant decrease over time. CI children spent less time with the robot each week and launched fewer applications. We must acknowledge that children were expecting a more advanced robot, similar to those depicted in movies, equipped with artificial intelligence (AI), and capable of fluent conversation. Indeed, the current underdevelopment of SARs for children led to some disappointment and general weariness among our CI children over time, providing thus an overall insight into the technological capabilities of and robot acceptance among CI children [5].

We additionally aimed to identify factors influencing the perceived interaction of CI children with the humanoid robot.

Firstly, the humanoid robot was well-received by almost every child, although "older CI children" showed less interest compared to the younger children. The parents generally expressed positive perceptions and acceptance of the robot. The decline in robot usage observed in our study could be attributed to the shared observation reported by both children and their family members. Indeed, we observed that while the robot initially sparked interest and enjoyment, this enthusiasm dwindled rapidly due to a lack of updates and internet connection. This initial phase provides crucial insights into the acceptability of a humanoid robot in a home environment. Additionally, it highlights the scarcity of studies exploring the long-term assessment and follow-up of the acceptability of humanoid robots by CI children and their parents [9].

Secondly, our findings also suggest that age has a significant role in how the children with CI perceived and evaluated their interaction with the humanoid robot at home.

Younger CI children exhibited a higher level of acceptability toward the robot. This finding should be considered for the future design and implementation of robot-assisted interventions for children with hearing impairments. Further research may delve deeper into understanding the specific factors that contribute to the differences in perception and how interventions can be tailored to better address the needs of CI children. Considering that factors such as age and social factors can affect speech development after implantation [10], early implantation followed by complementary remote speech-language training with a humanoid robot could be crucial for maximizing benefits and reducing the shortage of access to hearing care professionals for families in areas affected by medical desertification [1]. Looking ahead, in line with the findings from Ioannou and Andrevia [13], Uluer et al.[14], and our own research here, the development of a humanoid robot tailored for remote home training of deaf and implanted children holds the promise of being a significant therapeutic and technological breakthrough. Such a device has the potential to enhance quality of life and independence of these patients, while at the same time facilitating training, particularly in remote areas.

Several limitations in the current study could be addressed in future research. Firstly, we observed a series of technical and social challenges that would affect CI children and their parents acceptance and adoption. Previous studies indicated that people expect robots to have social traits that help them empathize with people [21]. Secondly, future studies should aim to recruit younger children to broaden the scope of the research. Additionally, it would be beneficial to offer more frequent updates (such as conversations, games, and music) for the robot during its time at home. This could potentially enhance the duration and frequency of robot usage. We also found that children, and especially parents, expected the humanoid robot to have a greater diversity of functions, including high social intelligence, integration of AI, a voice assistant (e.g. Alexa; Google Home), and integration of Natural Language Processing (NLP). Furthermore, the behavioral patterns of parents and children can mutually influence each other in diverse ways. Whether engaged in child-technology interaction or not, parents play a pivotal role by offering support and guidance to their children. This, in turn, has a consequence on the behavior patterns and attitudes of the children towards technology.

For our next studies, we plan to implement speech-language training exercises within the robot. Our goal is to personalize the difficulty levels of these exercises based on each child's profile and specific needs for complementary remote speech-language training. Finally, improving the speech comprehension capacity of the robot could enhance the perceived interaction between CI children and the robot, but also with their parents. Addressing these limitations would contribute to a deeper understanding of the benefits of humanoid robots as a remote speech-language training tools for CI children at home.

VIII.CONCLUSION

In conclusion, this study is the first step towards using a home-based humanoid robot as a remote speech-language

training tool for deaf children with cochlear implants. Specific characteristics of CI children and the robot are required to enable good interactions with the humanoid robot at home, such as younger CI children and access to a diversity of applications, but keeping the personalization of the robot and proposing updates of functionalities for home training.

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