Nonword repetition in children with cochlear implants using different speech and language rehabilitation approaches

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ABSTRACT

When a child is diagnosed with hearing impairment, early intervention should be provided to avoid language deprivation and its consequences. This study investigates the contribution of two spoken language rehabilitation approaches to speech development in children with cochlear implants (CI) using a nonword repetition task. Cued Speech (CS) is a multisensory communication tool, facilitating speech perception by providing access to all phonemes. Auditory Verbal Therapy (AVT) is a hearing-focused method, training auditory skills to boost speech perception. Earlier studies have reported that CS and AVT improve phonological skills in a picture-naming task. In this study, using a nonword repetition task, we show that the number of consonant and vowel errors is higher in children with CI than in typically-hearing peers, independently of the rehabilitation method. Therefore, children with CI may have hidden speech processing difficulties that remain undetected in lexical speech tasks but can be revealed by nonword repetition.

Keywords: Nonword Repetition, Children, Cochlear Implants, Cued Speech, Auditory Verbal Therapy

1. INTRODUCTION

Hearing loss can have impacts on many aspects of language, communication and cognition. Therefore, it represents a major social issue. The developmental trajectories of deaf children are varied and different communication modalities can be adopted. Some families choose to use sign language, which is fully accessible to deaf people in terms of perception and production, while others prefer to focus on spoken language communication, especially when it is the parents' mother tongue (95% of deaf children have at least one hearing parent, cf. [1]). A large proportion of French-speaking children with profound hearing loss who receive oral education are usually fitted with a cochlear implant (CI), a widely used device which partially restores access to speech sounds. However, the perception of some acoustic features may still be altered, which results in limited phonological skills [2–4] and may impact spoken language development [5]. Other repercussions have also been found in the speech production of French-speaking children with cochlear implants, especially on voicing contrast [6], and place of articulation ([2], [4] , [6]).

To compensate for the acoustic deficits associated with cochlear implants, different spoken language rehabilitation approaches can be used.

Cued speech [7] is one of the communication tools used by professionals and parents in France. It is a multisensory approach, as manual gestures are added to audio-visual speech communication. Each phoneme of a given language is associated with a manual cue produced near the speaker's face, simultaneously with speech production. Many studies have shown that cued speech use improves speech perception in children with hearing impairment, when audiovisual speech is presented together with manual cues [8], and even visual speech perception without auditory information [9]. More importantly, longer-term effects have also been demonstrated. For children educated with cued speech, improvements in speech perception have been observed in the visual-only, audio-visual and even audio-only (i.e. speech presented *without* simultaneous manual gestures) modalities [10], [11]. Several studies also suggest that cued speech exposure supports the development of more accurate phonological representations and improves phonological awareness, which promotes phonological memory, reading and spelling skills [12], [13]. More recently, using a picture-naming task, Machart et al. (2022) have shown that cued speech proficiency improves speech production in children with cochlear implants, especially with regard to voicing, nasality, manner and place of articulation [14].

On the other hand, Auditory Verbal Therapy (AVT), a hearing-focused approach is beginning to be used in France, mainly by parents who learn about through social network. Indeed, a recent study [15] shows that very few professionals in France are trained for this method and that more than half of the parents using this method in France became aware of it through social networks. AVT is a listening and spoken language early intervention program for deaf children, that focuses on the training of auditory

skills. It is a family-centred coaching program where parents are encouraged to use auditory verbal strategies in everyday life in order to stimulate their child's auditory skills. Each AVT session includes exercises aimed to promote the child's listening skills, and assessments are systematically conducted during these activities to adjust the objectives and provide parents with continuous feedback on the child's progress. Furthermore, during the sessions, four auditory exercises are usually conducted, which include sound detection, discrimination, identification, and comprehension. Although AVT is widely used and government-funded in several countries, scientific evidence on the contribution of AVT on speech and language development is still scarce. In a systematic review, Binos et al. (2021) [16] examine eight papers published in the last ten years, and they conclude that "although recent evidence from the published papers that were reviewed revealed the positive role of AVT with regard to the speech and language skills of CI children, it is still difficult to generalize", because of "lack of well-controlled studies" (absence of a control group, bias in participants' ages, etc). Some results are also contradictory, with e.g. Percy-Smith et al. 2017 [17] evidencing higher performance for children with AVT than children with "standard" Danish speech therapy, whereas Yanbay et al (2014) found no significant difference between groups of children with cochlear implants enrolled in AVT or other programs (oral communication or bimodal bilingual) [18].

The aim of the present study was to measure the influence of Cued French (French version of cued speech) and AVT on speech perception and production in children with cochlear implants, using a nonword repetition task. Indeed, nonword repetition has been shown to be an effective task to distinguish typical from atypical language development in children [19], a potential predictor of phonological, syntactic and lexical difficulties in deaf children [20], [21]. Lastly, it can also be used to evaluate the effectiveness of a communication mode [22]. Nonword repetition can be challenging as it involves many operations, including auditory perception, as well as verbal working memory, parsing of speech into phonological units and speech motor planning and programming.

2. METHODS

The data presented here are taken from a larger set of experiments designed to assess speech perception and production in children with typical development and children with speech sound disorders (the EULALIES project, [19]). Only the results of the nonword repetition task in children with cochlear implants (CI) and a group of children with typical hearing are reported here. Accuracy of consonant and vowel production was examined. The children with CI were divided into three groups, based on their modes of communication (AVT, proficient Cued French, no/little Cued French).

2.1. Procedure

This study used the nonword repetition task from the EULALIES battery, which includes all French phonemes in 16 nonwords. Each nonword consists of two to four syllables with various degrees of complexity (with or without clusters) and some nonwords include a morpheme or a lexical unit. The children sat in front of a computer screen and watched a video of a speaker producing the nonwords (sound + face of the speaker) and were asked to repeat them. The nonwords were presented as the names of cute monsters displayed on the screen. The children wore a SHURE headset microphone (Beta 54R) and a backup microphone was also placed on the table (Zoom recorder H4n Pro). Four inclusion tasks were also administered: a visual span (PathSpan, [23]), a digit span (ODEDYS, [24]), a language production task (morphosyntax task from ELO, [25]), as well as an auditory screening test for children with typical hearing, to exclude any hearing disorder (perception at 20 dB on the frequencies 250, 500, 1000, 2000, 4000 and 8000 Hz, using an Electronica 9910 audiometer). Children with typical hearing were excluded from the study if their scores were below the norm.

A fifth task was used for children with CI exposed to cued speech to measure their level of cued speech proficiency, using the TERMO test (Evaluation test for the reception of the oral message by the deaf child; [26]). The experimenter presented a list of words and sentences using Cued French gestures without phonation in order to measure the child's cue reading skills without the auditory modality. The child was asked to repeat the items vocally. Only lexical accuracy was assessed (the phonological aspect of their production was not considered). Two levels of cued speech proficiency were determined: low Cued French reading skills (CF-) and high Cued French reading skills (CF+). Children in the CF- group could at most understand a few familiar words (or none) at slow speech rate. Children in the CF+ group could understand familiar words and simple sentences at natural speech rate.

Parents or caregivers provided informed consent and filled a questionnaire on their child's language development and background (multilingualism, age

of first fitting, communication tools used at home, information about the child's deafness). Data were collected anonymously, according to GDPR regulations. The study received ethical approval from the local ethics committee (CERGA-Avis-2022-23).

2.2. Participants

This study includes 119 children (63 girls and 56 boys) aged between 66 and 140 months, with 83 children with typical hearing skills (TH group) and 36 children with cochlear implants (CI group). Only monolingual children were included in this study, i.e. children who were not exposed to a language other than French on a daily basis. The CI group was divided into three subgroups, based on their modes of communication (AVT, CF+: proficient Cued French, CF-: no/little Cued French). Age characteristics are given in Table 1.

	N	Age	Age at implantation
CF+	6	77-132 *(101.17; 18.55)*	12-85 *(28.67; 25.53)*
CF-	21	65-139 *(95.71; 22.09)*	11-90 *(28.86; 21.13)*
AVT	9	66-114 *(81.67; 16.68)*	11- 48 *(20.11; 10.64)*
TH	83	61-131 *(84.67; 15.57)*	

Table 1: Chronological age and age at implantation in months for the 4 groups of participants (minimum-maximum *(mean; sd)*).

The children exposed to Cued French (CF+ and CF-) were recruited during the ALPC (Association Nationale pour la Langue Parlée Complétée) cued speech summer camp or through the Grenoble University Hospital. The children from the AVT group were recruited through the association ADEFAV (Association des Familles AVTistes) which promotes rehabilitation through hearing training. The 83 TH children (35 girls and 48 boys) belong to the large cohort of typical children of the EULALIES project [23]. All TH children were recruited from local schools.

2.3. Data processing and statistical analyses

The nonword repetition task was transcribed using a narrow phonetic transcription and processed with the PHON software [27]. All recordings were double-blindly annotated by two different transcribers who had no knowledge of the child's group membership or of the other person's transcription. A third transcriber then validated the transcriptions (in case of discrepancy, a consensus was reached), syllabified the items and aligned the production with the target.

The number of errors per nonword was extracted with PHON (total number of substitutions, deletions and epenthesis).

Statistical analysis and graphical representations were done using the R software [28]. Generalized Linear Mixed-Effects models with Poisson regression (glmer function) were used to analyze the number of errors on consonant and vowel production separately, in the four groups of children. A backward stepwise variable selection by model comparison was applied to identify the best-fitting model (anova function). Random-effect factors and fixed-effect factors of interest were included, with interactions. Random-effects factors were Participant and Item. Fixed-effect factors were Group (CF+, CF-, AVT and TH) and Chronological_Age (in months). Multiple comparisons were then performed with the glht function of the multcomp package in R. Factors which did not improve model fit were excluded.

3. RESULTS

3.1. Consonant errors

Figure 1 shows the mean number of consonant errors per nonword for each group (CF+, CF-, AVT, TH).

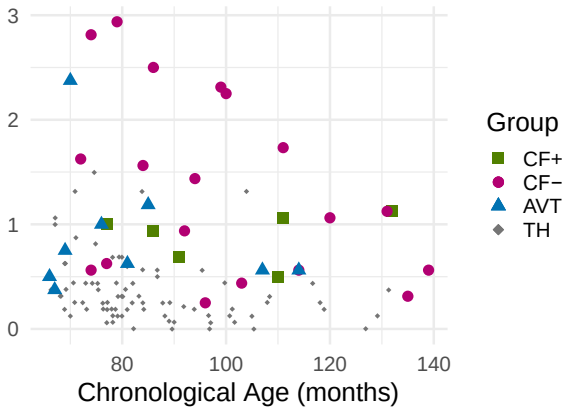

FIGURE 1: Mean number of consonant errors per nonword in the four groups of children, according to chronological age in months.

The best-fitted model for the analysis of consonant errors included *Group* and *Chronological Age*, without any interaction. Multiple comparisons showed that all groups of children with CI (i.e., CF+, CF- and AVT) have higher numbers of consonant errors per nonword than TH children (resp. $Z = 4.371$, $p < .01$; $Z = 8.307$, $p < .001$; $Z = 3.717$, $p < .001$). No difference was found between the groups of children with CI.

3.1. Vowel errors

Figure 2 shows the number of vowel errors per nonword for each group (CF+, CF-, AVT, TH).
The results for vowel errors per nonword did not differ from those of consonant errors. Indeed, the best-fitted model also included *Group* and *Chronological Age*, without interaction. Multiple comparisons also revealed that all groups of children with CI (i.e., CF+, CF- and AVT) have higher vowel error rates than TH children (resp. $Z = 5.421$, $p < 0.01$; $Z = 8.794$, $p < 0.001$; $Z = 5.341$, $p < 0.001$).

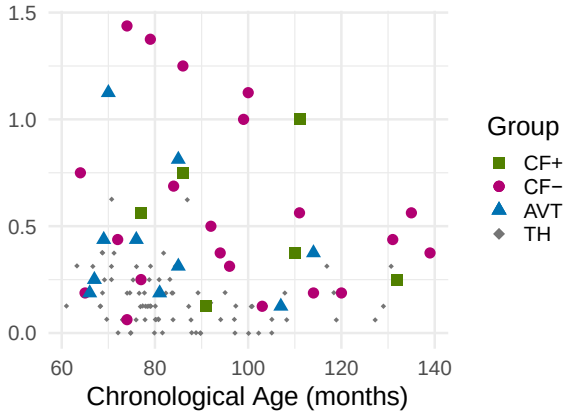

FIGURE 2: Mean number of vowel errors per nonword in the four groups of children, according to chronological age in months.

4. DISCUSSION

The aim of this study was to investigate the influence of two spoken language rehabilitation approaches on the nonword repetition skills of deaf children with CI. The results show that deaf children with cochlear implants do not achieve similar nonword repetition performance to their typical hearing peers, regardless of the spoken language rehabilitation approach. A significantly higher number of consonant and vowel production errors was found in all groups of children with CI (i.e., CF+, CF- and AVT) compared to children with typical hearing. These results differ from those of Machart et al. (2022) on a picture-naming task, who found that children with high Cued French proficiency had similar speech production performance to typical hearing peers, contrary to children with low cued speech proficiency [14]. It seems, therefore, that high Cued French proficiency allows more accurate speech production in children with CI for familiar words but not for unknown words.
Moreover, another study was carried out to assess speech perception using a lexicality judgement task, in the same groups of participants as the present study. The results showed that children in the AVT group performed closer to the TH group than the children in the CF+ group, who in turn outperformed children in the CF- group [29].
In sum, other studies have reported benefits of auditory-verbal therapy and cued speech proficiency for picture naming skills, i.e. for the production of well-known words, as well as for lexicality judgment, i.e., for the detection of phonological distortion on well-known words. Such a positive impact was not found in the present study, involving nonword repetition.
The nonword repetition task requires different skills than word perception and production. Phonological decoding, verbal working memory as well as generating unlearnt motor plans and programs are necessary additional levels of processing. Lexical support (use of semantic information to overcome phonological decoding difficulties) cannot be used in this task which involves unknown items. The nonword repetition task is a good way to assess these skills independently of stored lexical knowledge.
The results of the present study illustrate how some speech processing difficulties in children with hearing loss, which remain undetected when only lexical tasks are considered, can be revealed by a nonword repetition task. Identifying these difficulties is a crucial issue, as they can lead to cognitive fatigue and social insecurity. We argue that non-lexical tasks should be systematically used when evaluating the efficacy of a speech therapy method.
The nonwords used in this task included all French phonemes and consisted of sequences with various length, and syllable complexity. The specific features that hamper the performance of children with hearing impairment in this task will need to be further explored. These will be confronted with data from the word production and word perception tasks, in order to weigh the relative role of perceptual/motor difficulties.
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