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Audio-visual speech perception in prelingually deafened Japanese children following sequential bilateral cochlear implantation

Ryosuke Yamamoto [a], Yasushi Naito [a, *], Risa Tona [b], Saburo Moroto [a], Rinko Tamaya [a], Keizo Fujiwara [a], Shogo Shinohara [a], Shinji Takebayashi [a], Masahiro Kikuchi [a], Tetsuhiko Michida [c]

[a] Department of Otolaryngology, Head and Neck Surgery, Kobe City Medical Center General Hospital, Kobe, Japan
[b] Department of Otolaryngology, Head and Neck Surgery, Graduate School of Medicine, Kyoto University, Kyoto, Japan
[c] Department of Otolaryngology, Institute of Biomedical Research and Innovation, Kobe, Japan

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ABSTRACT

Objectives: An effect of audio-visual (AV) integration is observed when the auditory and visual stimuli are incongruent (the McGurk effect). In general, AV integration is helpful especially in subjects wearing hearing aids or cochlear implants (CIs). However, the influence of AV integration on spoken word recognition in individuals with bilateral CIs (Bi-CIs) has not been fully investigated so far. In this study, we investigated AV integration in children with Bi-CIs.

Methods: The study sample included thirty one prelingually deafened children who underwent sequential bilateral cochlear implantation. We assessed their responses to congruent and incongruent AV stimuli with three CI-listening modes: only the 1st CI, only the 2nd CI, and Bi-CIs. The responses were assessed in the whole group as well as in two sub-groups: a proficient group (syllable intelligibility $\geq$80% with the 1st CI) and a non-proficient group (syllable intelligibility < 80% with the 1st CI).

Results: We found evidence of the McGurk effect in each of the three CI-listening modes. AV integration responses were observed in a subset of incongruent AV stimuli, and the patterns observed with the 1st CI and with Bi-CIs were similar. In the proficient group, the responses with the 2nd CI were not significantly different from those with the 1st CI whereas in the non-proficient group the responses with the 2nd CI were driven by visual stimuli more than those with the 1st CI.

Conclusion: Our results suggested that prelingually deafened Japanese children who underwent sequential bilateral cochlear implantation exhibit AV integration abilities, both in monaural listening as well as in binaural listening. We also observed a higher influence of visual stimuli on speech perception with the 2nd CI in the non-proficient group, suggesting that Bi-CIs listeners with poorer speech recognition rely on visual information more compared to the proficient subjects to compensate for poorer auditory input. Nevertheless, poorer quality auditory input with the 2nd CI did not interfere with AV integration with binaural listening (with Bi-CIs). Overall, the findings of this study might be used to inform future research to identify the best strategies for speech training using AV integration effectively in prelingually deafened children.

1. Introduction

Many studies in the literature have addressed speech perception following sequential bilateral cochlear implantation (Bi-CIs) compared to unilateral cochlear implantations [1–4], but evidence about the contribution of audio-visual (AV) integration on speech perception in children following sequential Bi-Cis is scarce. Speech recognition in daily life is basically an AV phenomenon. When the face of the speaker is visible, the listener is able to extract information from the movements of the lips and tongue (lip-reading) and this interaction between the auditory and visual modalities contributes to speech perception especially in less than ideal conditions such as in noisy environments, with poor auditory input, or when using CI [5–9]. For example, a study on Japanese listeners

* Corresponding author. Department of Otolaryngology, Kobe City Medical Center General Hospital, 2-1-1 Minatojimaminamimachi, Chuo-ku, Kobe, 6500047, Japan.
E-mail address: naito@kcho.jp (Y. Naito).

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(age ranges from 22 years old to 27 years old) [5] showed that lip reading was helpful and improved speech intelligibility in noise compared to auditory stimuli alone. The study showed that the intelligibility of the syllable/pa/was 98% for auditory stimulation in quiet, decreased to 56% for auditory stimulation in noise (Gaussian noise with 50-kHz bandwidth; signal to noise ratios were kept at 0 dB), and increased to 98% for AV stimulation in noise. Moreover, the value of AV integration in speech perception with CIs was shown in English congenitally deafened children with unilateral CI [9]. Similarly, it might be that AV integration is important for speech perception in Japanese congenitally deafened children with CIs, but this has not been fully investigated yet.

The importance of investigating AV integration abilities, especially in children, is also due to the fact that AV speech perception is related to language development in children [10]. AV speech perception is critical in many aspects of perceptual, cognitive, and social learning during child development and requires many years of experience and feedback [10]. So, the assessment of multisensory speech perception in developing children may reveal important aspects related to speech perception and, more generally, to language development [10].

In the assessment of AV integration, the analysis of the McGurk effect can provide important information. The effect was for the first time documented by McGurk and MacDonald [11] who reported a multisensory (AV) illusion occurring with AV speech stimuli when the auditory stimulus and the visual stimulus were incongruent. Specifically, they recorded a voice articulating a syllable and dubbed it with a face articulating a different syllable. In normal hearing listeners, syllables that were well recognized in the auditory modality were recognized as different syllables in the AV modality when the auditory stimuli were dubbed with incongruent visual speech. The McGurk effect can be defined as an acoustic utterance that is perceived as a different utterance when presented with incongruent visual articulation [12]. The McGurk effect is the result of multisensory (specifically, AV) integration and, as such, it can be used as an indirect measure of AV integration [12].

In general, the responses to AV stimuli are influenced by three factors: AV integration abilities, auditory perception abilities, and visual perception abilities. Any factor that influences any of these abilities (auditory, visual, or AV integration) can influence speech perception in the AV modality. Speech recognition can be, for example, affected by CI proficiency, by the quality of auditory input [13], as well as by the quality of visual input as shown, for example, in children with CIs [14]. When the McGurk effect is elicited, the listener's response can change depending on the relative influence of auditory and visual perceptions. The listener's response can range from perceiving the acoustic stimulus (when the auditory modality prevails over the visual), to 'fusion' perception (when the auditory and visual modalities are balanced and lead to a combined effect), to perceiving the visual stimulus (when the visual modality prevails over the auditory) [12]. This variability in response to incongruent AV stimuli is called McGurk susceptibility (or AV integration ability) and is characterized by high inter-individual variability [10].

The McGurk effect is more easily observed in phonologically complex languages (e.g., English, Italian, Spanish). Also, it is more easily induced with low signal-to-noise ratios, and it increases with advancing age, as shown in English-speaking normal-hearing children [15]. In general, native English listeners show strong McGurk effect for highly intelligible auditory speech stimuli. On the other hand, Japanese listeners have been reported to be less subject to the McGurk effect [5,15,16]. This might be related to the fact that Japanese listeners typically do not use visual cues as much as, for example, native English listeners, unless auditory stimuli become difficult to hear, for example due to noise or foreign accent [5,16].

Several studies have shown that cochlear implantation can lead to stronger AV integration [17–19]. Following implantation, postlingually deafened adult CI recipients have been seen to maintain enhanced speechreading abilities [19] and to rely heavily on visual speech information in AV conditions [17–19]. Prelingually deafened children with a unilateral CI are also likely to make better use of AV integration than normal hearing controls [8,20]. This was also shown in Japanese children. Specifically, Tona et al. [21] showed that prelingually deafened children with a unilateral CI whose native language was Japanese were better at AV integration than normal hearing age-matched control subjects [21]. In the study [21], most of children with normal hearing (age range, 4–11 years; median age, 6 years) showed auditory responses to incongruent AV stimuli, on the other hand, most of children with a unilateral CI (age range, 4–10 years; median age, 6 years; monosyllable speech perception test score range, 80–100%) showed McGurk effect to some incongruent AV stimuli, such as a combination of auditory/ba/ and visual/ga/, and a combination of auditory/pa/and visual/ka/. Behavioral evidence in prelingually deaf pediatric CI users has indicated that superior speechreading abilities before implantation may relate to future auditory-only language abilities with a unilateral CI [8]. This might be due to the fact that speechreading may enable early access to spoken language structure and facilitate the development of general linguistic skills in children such as phonological processing [8].

The McGurk effect develops with age and experience. The original study [11] included both adults and children and showed that children of 3–5 years and 7–8 years had lower influence of visual perception on the McGurk effect compared to adults, whereas identification of auditory-only stimuli was equal among the three groups. Bergeson et al. [8] showed that AV sentence comprehension consistently improved over a 5-year period after CI fitting in a large group of prelingually deafened children with a unilateral CIs.

Several studies suggest that there is a limited period for development of AV integration in children [6,20], so timely intervention and rehabilitation are crucial. Schorr et al. [6] reported that prelingually deafened children who received unilateral CIs after 2.5 years of age exhibited limited or absent AV integration abilities. Another study, which assessed the cortical auditory evoked potential as indices of cortical maturation, showed that children implanted later in childhood (>7 years) had abnormal electroencephalograms, whereas children implanted earlier in childhood (<3.5 years) had normal electroencephalogram [20], suggesting the importance of early intervention in children. The cortical networks for auditory speech processing, once completely developed, remain intact in postlingually deafened patients [22]. However, in prelingually deafened individuals, these cortical networks may not develop completely, even when CIs are fitted early during the speech acquisition period [22]. The temporal auditory cortex of a deaf child begins to process language perceived with visual modality if the quality of auditory signals is poor, thus making the child dependent upon visual cues for speech listening. This cross-modal plasticity might be limited to favor normal auditory cortex development with the help of hearing prosthesis (e.g. hearing aids, CIs, or other implantable devices to restore hearing), supporting development and acquisition of listening and spoken language skills [22]. Hearing aid fitting or cochlear implantation are not sufficient, per se, for the development of listening and spoken language abilities as speech and language practicing is a key aspect. In fact, if children with CIs do not practice listening and speaking abilities in their daily life, speech perception with the visual modality might prevail and the networks for spoken language processing in the superior temporal cortex might not develop sufficiently [23].