Multimodal Sensorimotor Investigation of Audio-Visual Integration in Cochlear Implant Users

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1 Introduction

Humans achieve greater precision when synchronizing their movements with rhythmic sounds compared to visual events. This advantage is believed to arise from the superior temporal processing capabilities provided by the auditory system in combination with the coupling between auditory and motor systems [1]. However, the extent of this auditory advantage can be affected by experience and the nature of the stimulus [2].

Deaf individuals exhibit superior synchronization of movements with visual timing cues compared to normal hearing (NH) individuals [3], whereas cochlear implant (CI) users are able to move in time to the beat of music, although not as well as NH controls [4].

This study aimed to test whether CI users retain an advantage for visual synchronization from their pre-implant deafness, while presenting auditory synchronization ability comparable to those of NH individuals, or if the neural reorganization after implantation reverts any visual synchronization advantage acquired pre-implantation. Specifically, we measured both unimodal and multimodal auditory and visual synchronization abilities in a cross-sectional sample of CI users compared to NH controls using a standard sensorimotor paradigm.

2 Material and method

2.1 Participants

Twenty adult CI users with a mean age of 43.2 years (SD 15.0; 15 females) and seventeen paired NH participants who were age and gender matched (mean age of 41.1 years; SD 15.5 years; 12 females) were recruited for this study. Three CI users did not have a pairwise NH match; there were no group differences on age or gender balance. CI users were recruited through the Raymond-Dewar Institute (Montreal, QC, Canada) and the MAB-MacKay Rehabilitation Center (Montreal, QC, Canada), two centers offering rehabilitation programs for the hearing impaired. All participants provided written informed consent in the study and were compensated for their participation. The study was approved by the Research Ethics Board of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR).

2.2 Experimental Procedure

The experiment was divided into four blocks, each consisting of twenty trials. The first two blocks contained detection tasks. The third block included ten trials from each of the two single modality synchronization conditions, and the fourth included ten trials from each of the two multi-modal synchronization conditions. There were four different conditions: auditory-only, visual-only, synchronous audio-visual and asynchronous audio-visual.

Auditory stimuli consisted of a metronome sequence containing a repeated six msec broadband percussive sound (200 Hz - 10 kHz) with a total sequence duration of 39.5 sec. The rate of the metronome was 2.4 Hz. The stimulus was generated using Matlab R2007a (MathWorks, Natick, MA, USA) and presented with two 8040A bi-amplified loudspeakers (Genelec, Natick, MA, USA) located at 1.5m on each side of the participant at a global sound pressure level of 70 dB SPL.

Visual stimuli were produced by a square matrix (3.7cm x 3.7cm) of blue light-emitting diodes located in front of the subjects at a distance of one meter. The LED square produced flashes at a frequency of 2.4 Hz (15 msec ON time) for the visual-only and synchronous audio-visual conditions. In the asynchronous audio-visual condition, the frequency was 2.6 Hz. A RX6 signal processing system (Tucker Davis Technologies, Alachua, FL, USA) was used for sub-millisecond precision of stimulus presentation.

Participants were instructed to tap their finger once every two beats while synchronizing with the sequence. They were specifically instructed to initiate their taps on the third beat. The experiment was self-paced, and participants had to press the 'enter' key on a keyboard to launch the next trial. Throughout the task, regardless of stimulus modality, participants were instructed to maintain their gaze on the center of the LED-square designed for presentation of the visual stimuli.

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There was a mandatory break after the 10th trial. Participants' tap responses were recorded using a force-sensitive resistor interfaced with the RX6 signal processing system, while sitting comfortably inside a double-walled audiometric booth.

3 Results

Figure 1 compares unisensory synchronization performance results between auditory and visual stimuli in both groups and Figure 2 presents multisensory performance in the synchronous and asynchronous conditions. In both groups, synchronization consistency was greater for auditory stimuli than visual stimuli. CI users and NH individuals exhibited similar unisensory performance within the visual and auditory conditions. In the multisensory conditions with concurrent auditory and visual stimuli, synchronous stimuli improved performance above the unisensory visual condition in NH individuals, but CI users did not display the same improvement. Moreover, interference from incongruent auditory information in the asynchronous condition was comparable in NH individuals and CI users.

4 Conclusion and Future Work

Despite known impairments in pitch processing, CI users exhibit relatively preserved rhythm processing. As hypothesized, comparable auditory rhythmic synchronization abilities were found in CI users relative to NH individuals, consistent with existing research. Notably, unlike deaf individuals, CI users did not present an advantage for synchronizing with visual rhythms compared to auditory rhythms, likely due to neural reorganization following implantation. The difference in multisensory audio-visual processing in CI users suggests that post-implant reorganization in sensory cortical regions may affect the integration of temporal auditory input from the implant with visual information. Together, these results offer a view into the impact of cochlear implants on audio-visual synchronization abilities, and emphasize the need to further investigate the neural mechanisms involved in post-implantation reorganization and its effects on sensory integration.

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References

[1] S.A. Whitton, and F. Jiang. Sensorimotor synchronization with visual, auditory, and tactile modalities. *Psychological Research*, 87(7):2204–2217, 2023.

[2] T.B. Janzen, Y. Koshimori, N.M. Richard, and M.H. Thaut. Rhythm and Music-Based Interventions in Motor Rehabilitation: Current Evidence and Future Perspectives. *Frontiers in human neuroscience*, 15:789467, 2022.

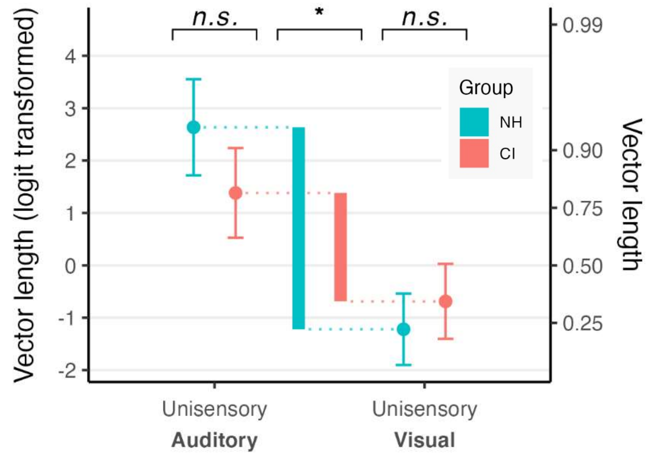

Figure 1: Synchronization performance in the unisensory auditory and visual conditions. Thick bars indicate the performance difference between auditory and visual conditions for each group. Analyses were performed on logit-transformed circular vector length; untransformed vector length values are indicated on the right axis for comparison.

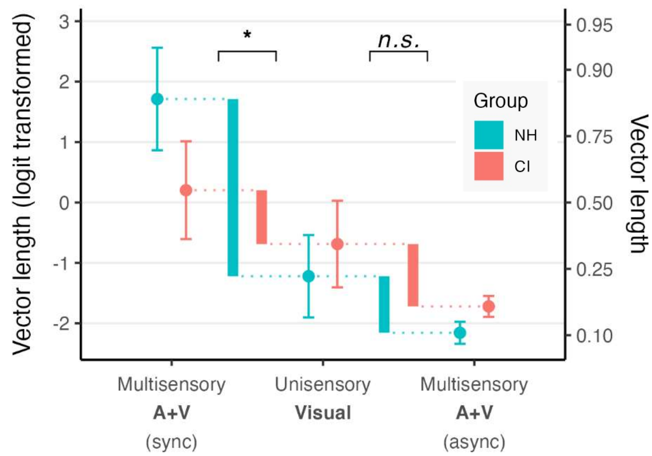

Figure 2: Synchronization performance in the multisensory auditory-visual conditions as compared to the unisensory visual condition. The left pair of thick bars indicates the increase in performance when synchronous (congruent) auditory stimulation was added, compared to visual-only, in each group. The right pair of thick bars indicates the decrease in performance when asynchronous (incongruent) auditory stimulation was added. Analyses were performed on logit-transformed circular vector length; untransformed vector length values are indicated on the right axis for comparison.

[3] J.R. Iversen, A.D. Patel, B. Nicodemus, and K. Emmorey. Synchronization to auditory and visual rhythms in hearing and deaf individuals. *Cognition*, 134:232–244, 2014.

[4] J. Phillips-Silver, P. Toiviainen, N. Gosselin, C. Turgeon, F. Lepore, and I. Peretz. Cochlear implant users move in time to the beat of drum music. *Hearing Research*, 321:25–34, 2015.