Electrophysiological Dynamics of Auditory-Visual Sensory Substitution

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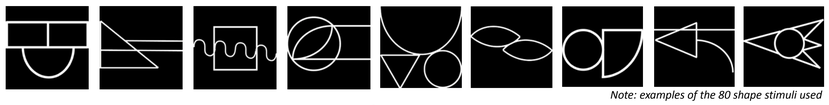
Background

- Previous brain-imaging studies[1,2] have suggested that auditory-visual sensory substitution training can lead to increased activation in visual processing areas in response to auditory stimuli.
- It is currently unknown, however, *when* in the sensory process activation of visual areas occurs.
- Here, we examine electrophysiological (ERP) changes due to auditory-visual sensory substitution training.

Essentially, our goals were to examine how learning to "hear shapes" changes the way the brain processes sensory information, and when in the time-course of stimulus processing these changes occur.

Stimuli



Note: examples of the 80 shape stimuli used

Meijer Image-to-Sound Conversion Algorithm[3]

1. The vertical dimension of the image is coded into frequencies between 500Hz-5000Hz, with higher spatial position corresponding to higher pitch.
2. The horizontal dimension is coded into a 500ms long left-to-right panning of the sound.

Methods

- 36 subjects (23 female, age 19-24) were randomly assigned to the Meijer group or the Control group.
- Each subject participated in 3 x 2hr sessions on 3 consecutive days.

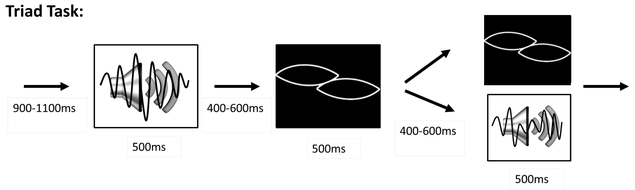
3 Experimental Sessions:

1. Pre-Training Phase: Triad Task (with EEG)

2. Training Phase: Meijer Training Transfer Test / Control Training Transfer Test

3. Post-Training Phase: Triad Task (with EEG)

Triad Task:



Respond **A** if any 2 stimuli match

OR

Respond **B** if no stimuli match

Training:

- **Passive Task:** Subjects exposed to 80 sound-image pairs (simultaneous audio-visual presentation).
- **5-Alternative Forced Choice Task:** Each sound followed by 5 images, one of which matched the sound (feedback provided).
- **Matching Task:** Each sound followed by 1 image. Subjects indicated "match" or "mismatch" (feedback provided). 20% of stimuli were novel.

Transfer Test:

Matching Task (no feedback) with 50% novel stimuli.

Control Group:

Sound and image stimuli identical to those presented to the Meijer group, but the specific sound-image pairings were random. Thus, each image had a unique sound, but their relationship did not follow the Meijer algorithm.

EEG Recording:

- 96 equidistant electrodes
- Average mastoid reference
- 500Hz sampling rate, 30Hz low-pass filter
- ERPs time-locked to onset of 1st stimulus (sound) and 2nd stimulus (image).

References

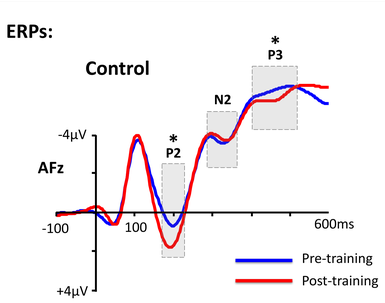
[1]Striem-Amit, E., et al. (2011). The Neural Network of Sensory-Substitution Object Shape Recognition, *Funct Neurol Rehabil Ergon*, *1(2)*, 271-278.

[2]Poirier, C., et al. (2007). What neuroimaging tells us about sensory substitution, *Neuroscience & Biobehavioral Reviews*, *31(7)*, 1064-1070.

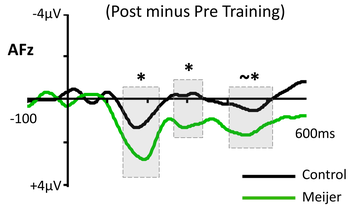
[3]Meijer, P. (1992). An experimental system for auditory image representations, *Trans. Biom. Eng., 39 (2),* 112-121.

EEG Results - Auditory

ERPs:

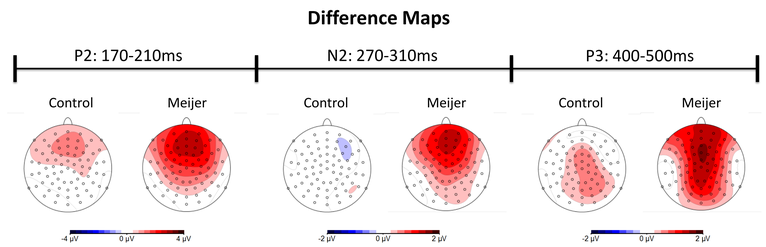


Difference Waves
(Post minus Pre Training)



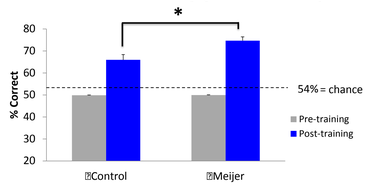
- Auditory stimuli elicited a more positive P2 and P3 after training in both groups ($p < .05$ for both).
- The P2 modulation was greater ($p < .05$) and the P3 marginally greater ($p = .06$) in the Meijer vs. Control group.
- An N2 amplitude difference pre vs. post-training was only evident in the Meijer group ($p < .05$).

Difference Maps



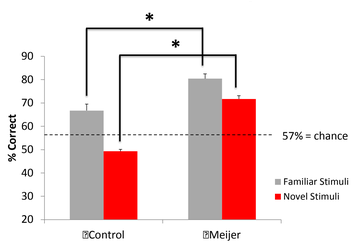
Behavioral Results

Triad Task Accuracy (Cross-Modal)



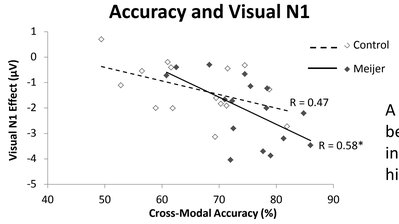
Cross-modal accuracy (number of correctly identified sound-image matches and mismatches) during EEG post-training was above chance for both groups, but significantly enhanced for the Meijer group ($p < .05$).

Transfer Test Accuracy



Meijer group performed markedly better than control group for both familiar ($p < .05$) and novel ($p < .05$) stimuli, with well-above-chance performance for novel stimuli (an indication of successful algorithm-based learning).

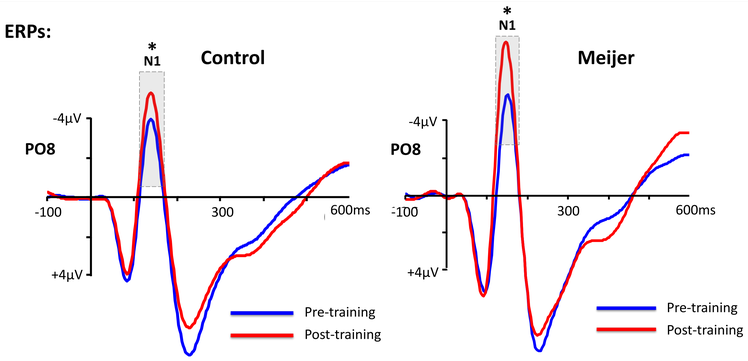
Correlation between Cross-modal Accuracy and Visual N1



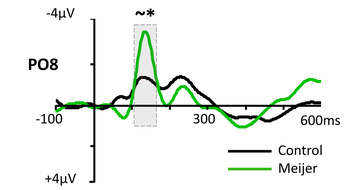
A significant correlation was found in the Meijer group between cross-modal accuracy and N1 amplitude, indicating that the better their performance, the higher the amplitude of the visual N1.

EEG Results - Visual

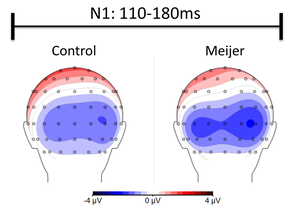
ERPs:



Difference Waves
(Post minus Pre Training)



Difference Maps



- Visual stimuli elicited a more negative N1 post vs. pre-training for both groups ($p < .05$ for both).
- The N1 amplitude enhancement was marginally greater for the Meijer group compared to the Control group ($p = .06$).

Conclusions

- Post vs. pre-training auditory P2 and P3 amplitude modulations were present for both groups suggesting that these ERP changes likely reflect general auditory perceptual learning. The amplitude differences were larger for the Meijer group, which may correspond to the enhanced learning made possible by training with the Meijer algorithm (as opposed to random pairings).
- A post vs. pre-training auditory N2 amplitude effect (270-310ms) was observed **only for the Meijer group.** The presence of this ERP change in the Meijer group along with the absence of a corresponding change in the control group suggests that this neural modulation may specifically reflect sensory substitution. Considering that the auditory stimuli were 500ms in duration, this effect is quite early (occurring prior to stimulus completion).
- Visual N1 amplitude (110-180ms) increased for both groups post vs. pre-training, but this increase was larger for the Meijer compared to the control group. This change in neural response may correspond to an enhancement of early LOC activity due to cross-modal learning.
- Overall, these findings suggest that sensory substitution training via the Meijer algorithm enhances the changes in electrophysiological activity that come about through cross-modal learning, and suggest a possible neural correlate (auditory N2) of auditory-visual sensory substitution that occurs very early in time.

Future Research

- How long does Meijer training last; does extended training further enhance these ERP effects?
- Are visual cortical responses to auditory stimuli (post-training) automatic or do they require attention?
- If ERPs were recorded for novel stimuli, how would the current pattern of results change?
- Are the ERP effects observed here mediated by mental imagery or direct cross-modal processing?