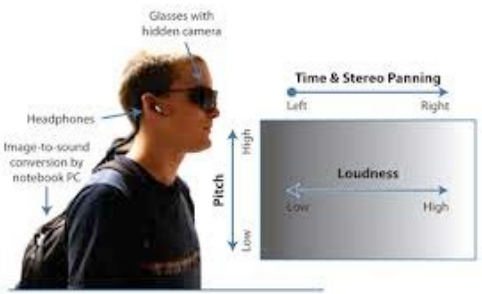
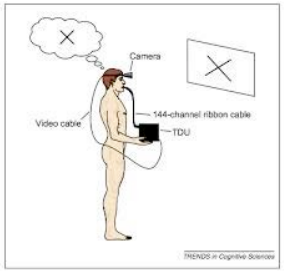
Studying the time course of sensory substitution mechanisms (CSAIL, 2014)

Christian Graulty, Orestis Papaioannou, Phoebe Bauer, Michael Pitts & Enriqueta Canseco-Gonzalez, Reed College.





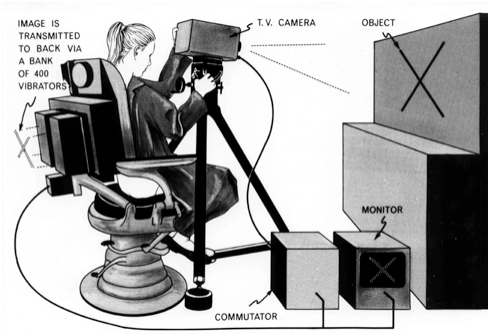
Funded by the Murdoch Charitable Program for Life Sciences and the Reed College Science Research Fellowship

Brain plasticity

"Changes in the brain due to: changes in behavior, learning, environment, brain injury or sensory deprivation"

- Neville and others examined how the blind use of occipital cortex to process tactile information and the deaf use auditory cortex to process visual information.

- Paul Bach-y-Rita (as early as 1969) showed that congenitally blind individuals could recruit tactile sensory systems as a substitute for vision (i.e. 'sensory substitution').



Neuroimaging studies

- Karns et al., (2012) measured the fMRI signal in deaf and hearing individuals during a multisensory (visual and tactile) processing task. The Heschl's gyrus (primary auditory cortex) and the superior-temporal gyrus (a secondary area) were recruited in deaf individuals to process non-auditory and cross-modal stimuli.

- Kim & Zatorre (2006, 2011, 2012) trained ***intact*** individuals to use vOICe, a sensory substitution device, to access *shape* information via sound. Increased post-training connectivity between primary auditory cortex and the lateral occipital complex (LOC), an area normally activated by shape processing (visual or tactile).

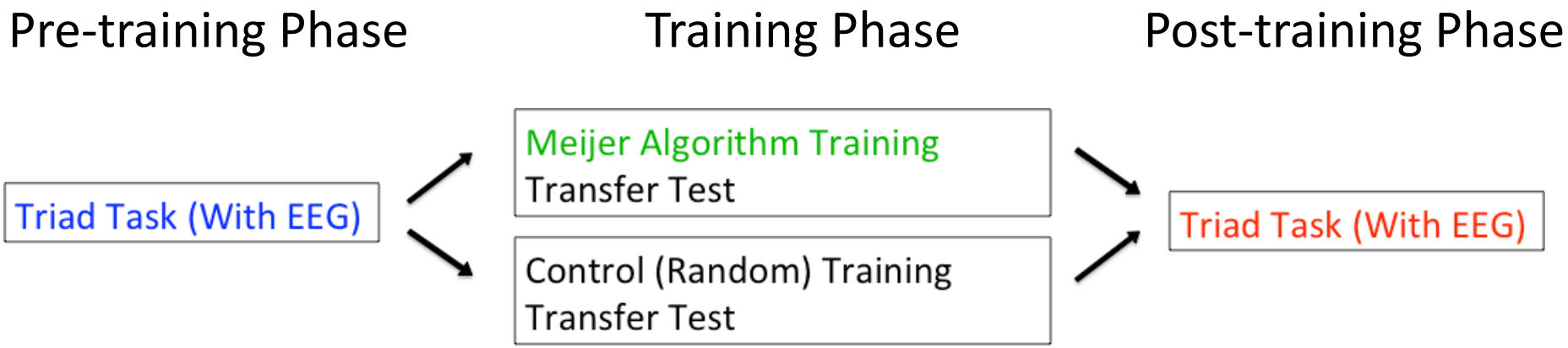
Our study

Simple strategy: Compare the brain electrical activity elicited by auditory and visual stimuli before *and* after intact individuals are trained to extract visual shape information from auditory stimuli.

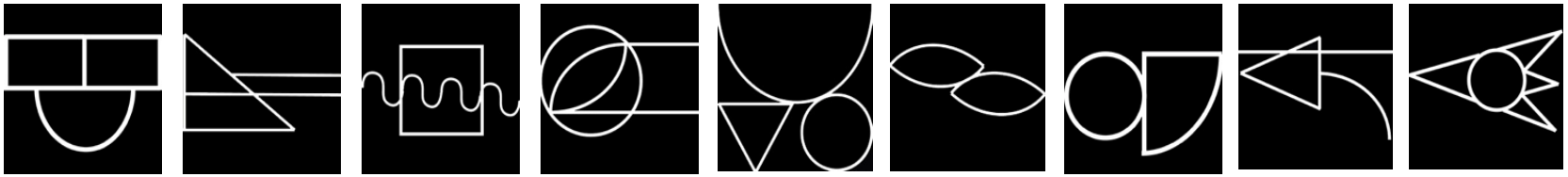
Methods

- Thirty-one participants (23 female, age 19-24) were randomly placed in the Meijer Algorithm group (N=16) or the Control group (N=15). Each subject participated in three 2-hour sessions on three consecutive days.

Overview of the three experimental sessions



Sample visual stimuli



180 complex shapes drawn using an “alphabet” of 13 basic shapes.

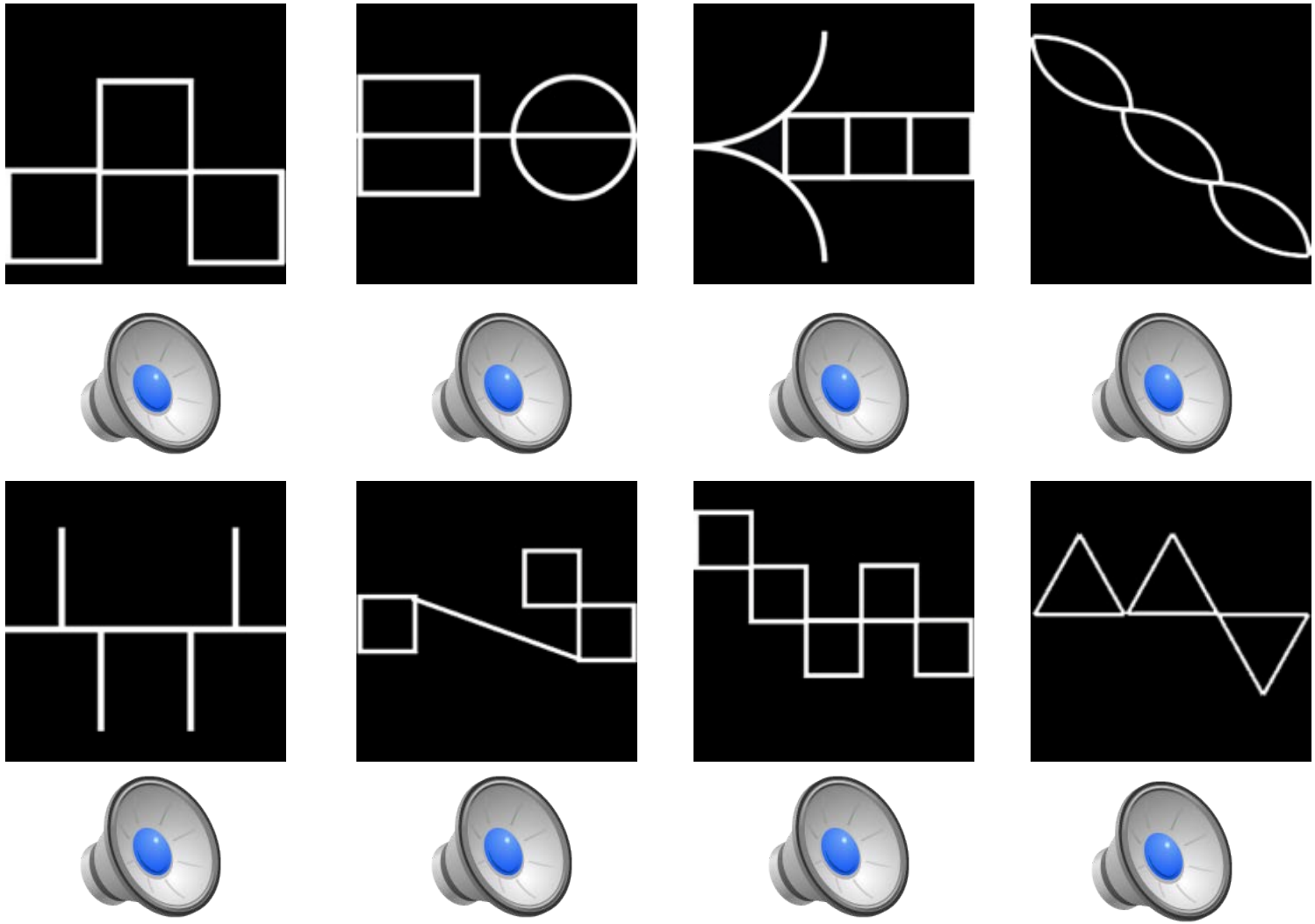
Meijer Image-to-Sound Conversion Algorithm

Auditory stimuli were translated from the shapes using the Image-to-Sound Meijer algorithm:

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 left-to-right panning of the sound.

Examples of the image-to-sound conversion



- Both groups went through the same three types of training and transfer test (to be explained).

- Difference between groups:

  Participants in the Control group were presented with **identical** sounds and images to the exp. group, but the sound-image pairings were random.

Training protocol

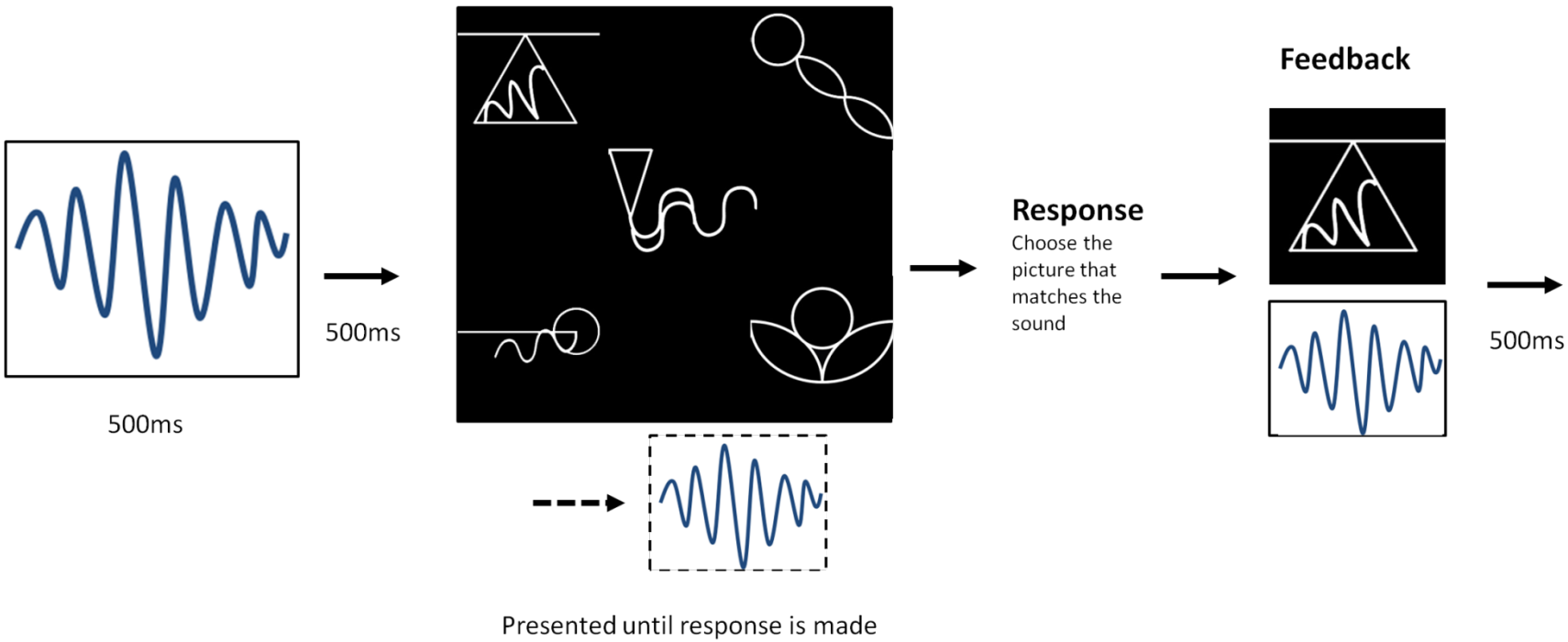
- Passive training. Passive exposure to 80 simultaneous image-sound pairs. Twice each for a total of 15 min.

- 5-alternative forced choice task (with feedback). 240 trials randomly selected. Around 30-50 min.

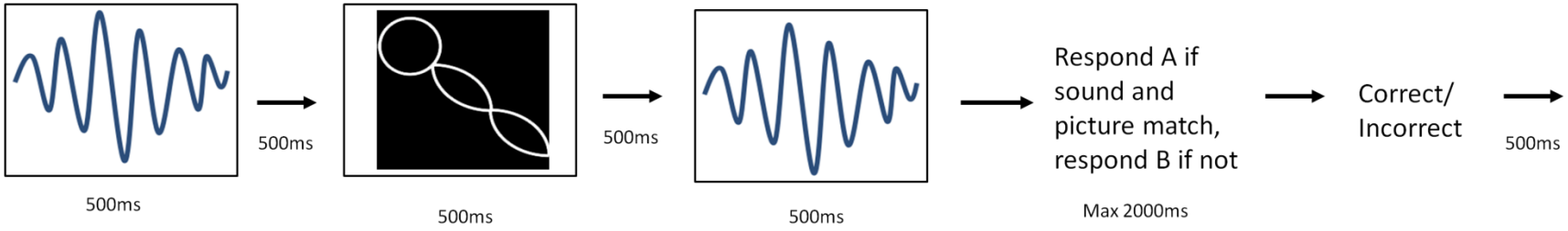
- Matching task (with feedback). 80 familiar pairs plus 20 novel (instructed to use rules or guess according to each group).

Transfer test (<u>without</u> feedback). Similar to matching task but no repetition of sound. 80 familiar and 80 novel sound-image pairs.

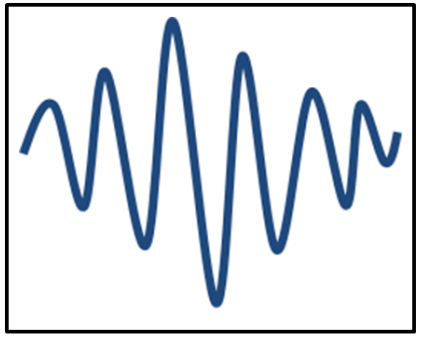
5-choice matching task



Matching task

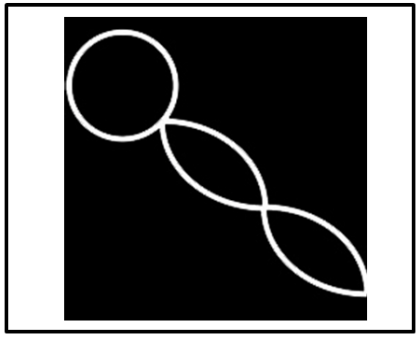


Transfer test



500ms

500ms



500ms

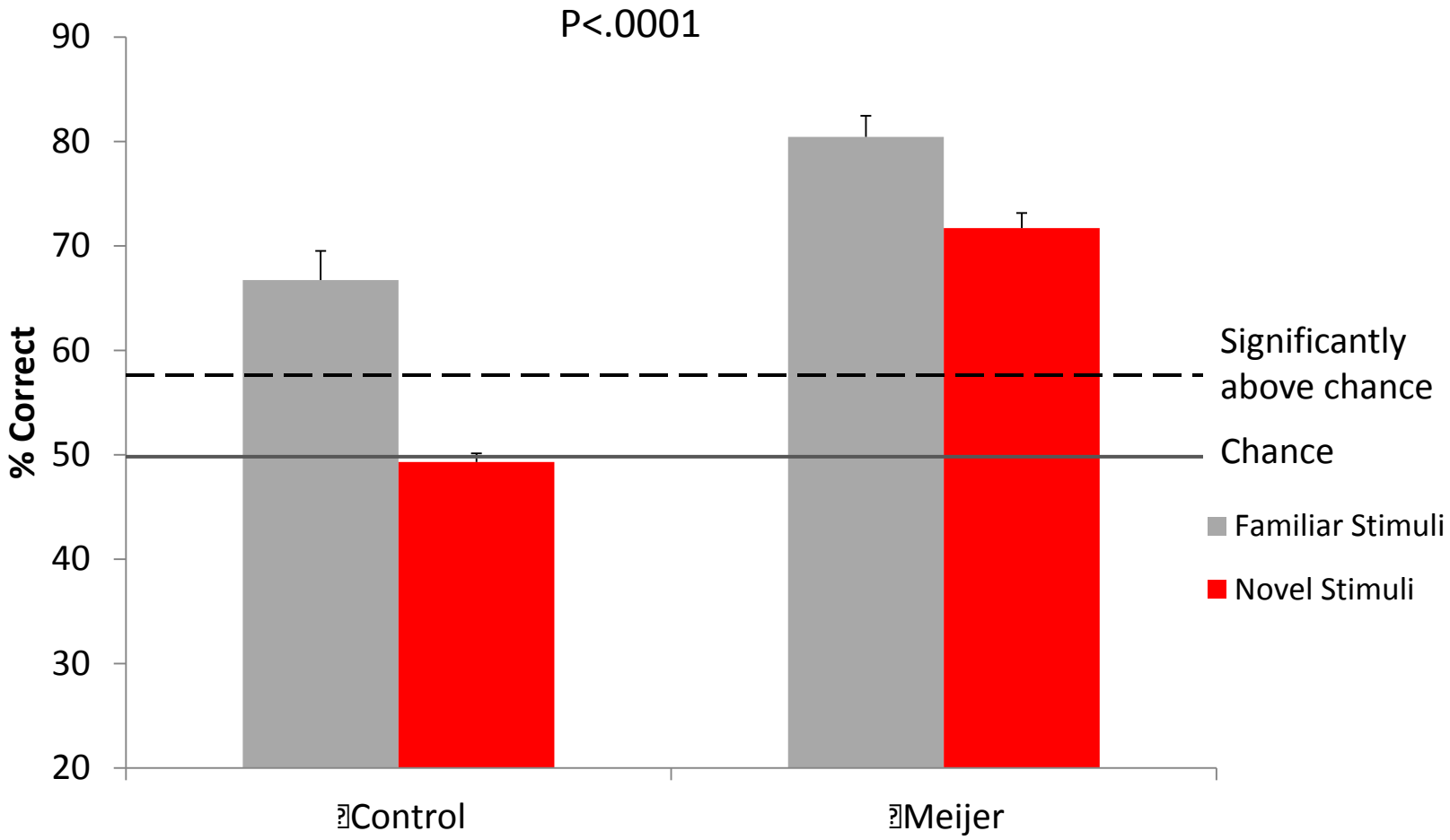
Respond A if sound and picture match, respond B if not

Max 2000ms

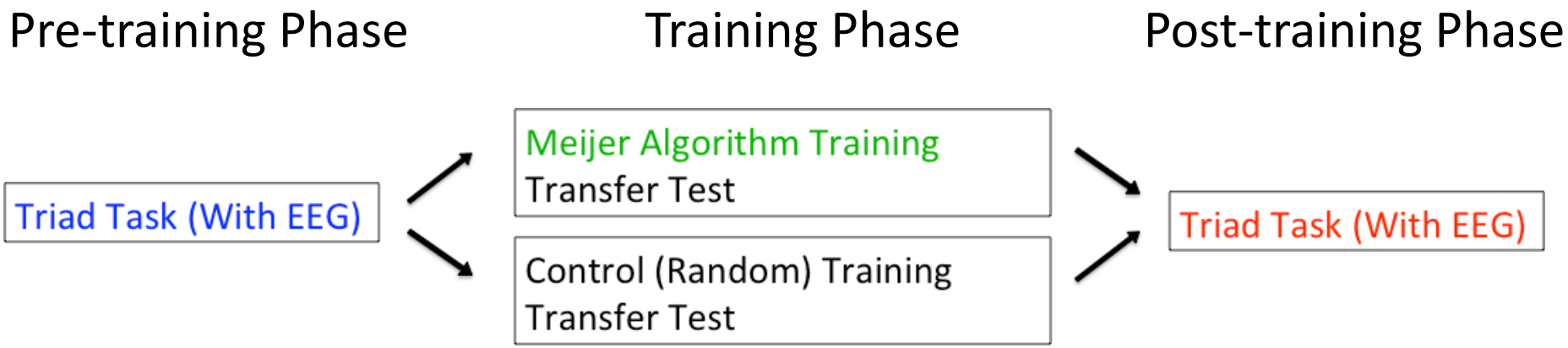
500ms

Behavioral Results
(effects of training)

Transfer Test Accuracy



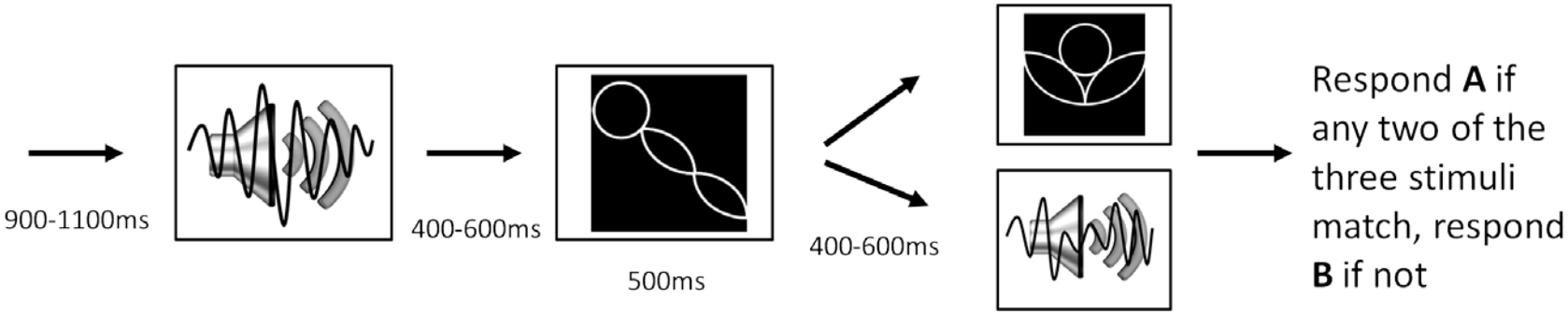
Overview of the three experimental sessions



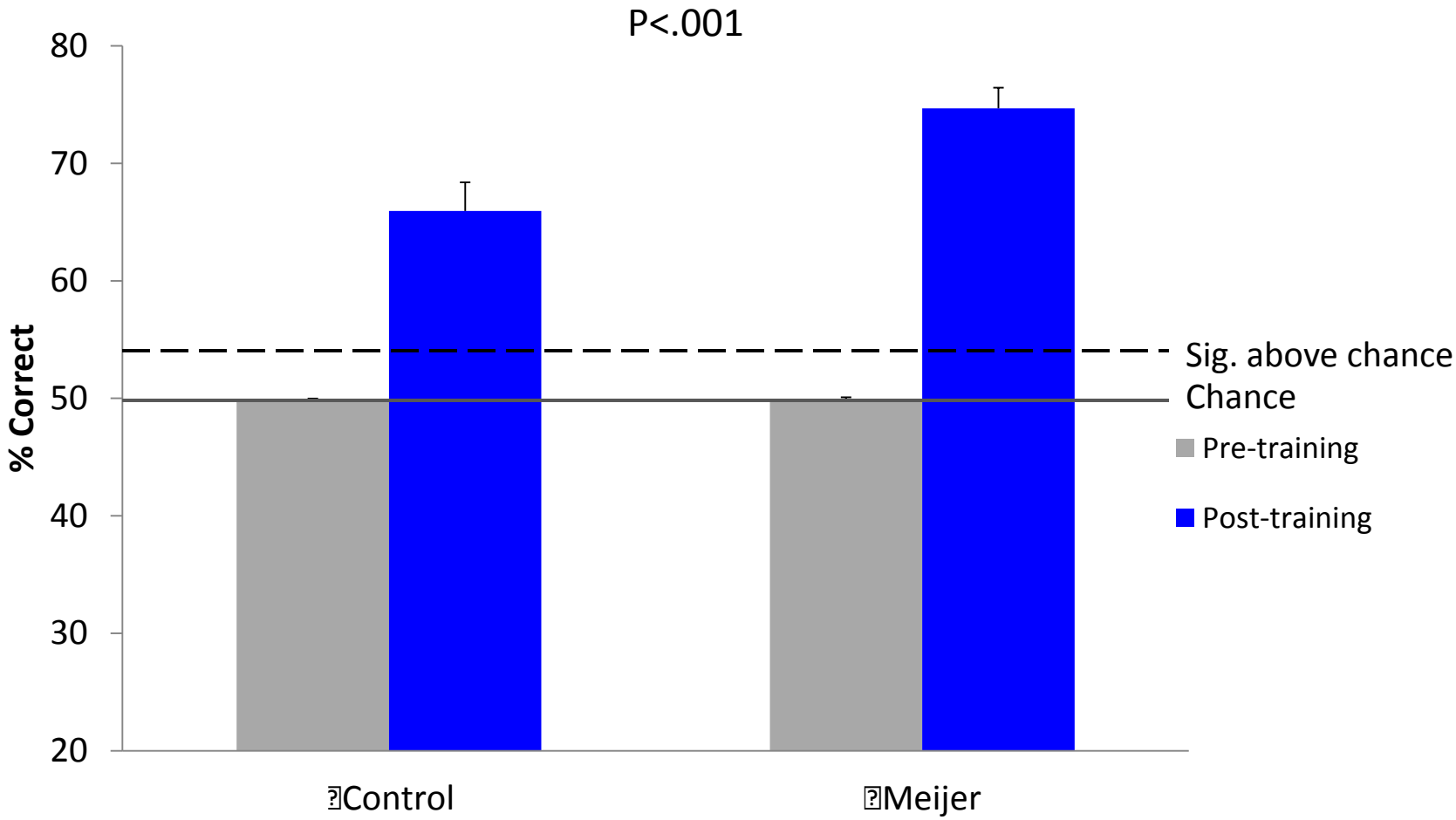
Triad Task (while recording EEG)

Pre-training: matching only within-modality

Post-training: Identical stimuli but now matching **within or across** modality



Triad Test Accuracy (only cross-modal trials)



Summary behavioral findings

- Both groups learned (trained) sound-image pairings. However, the Meijer group outperformed the control group.

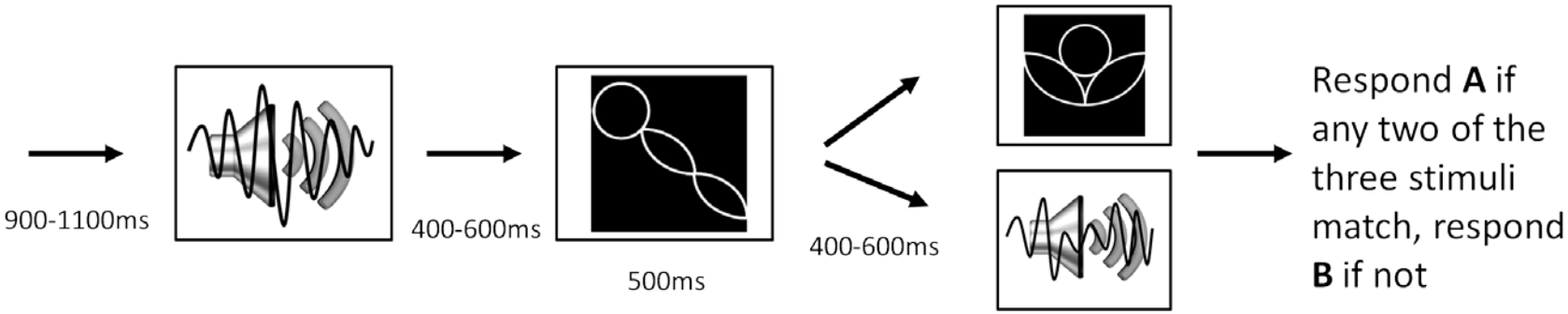
- The Meijer group was able to transfer their performance to new sound-image pairs.

- Post-training in the triad task, both groups identified sound-image pairs cross-modally. The Meijer group clearly outperformed the control group.

What about their pre- vs. post training ERPs in the triad task?

Triad task reminder

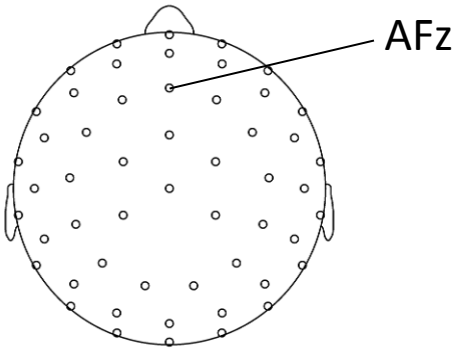
In the 1st and 3rd sessions we recorded EEG to identical auditory and visual stimuli

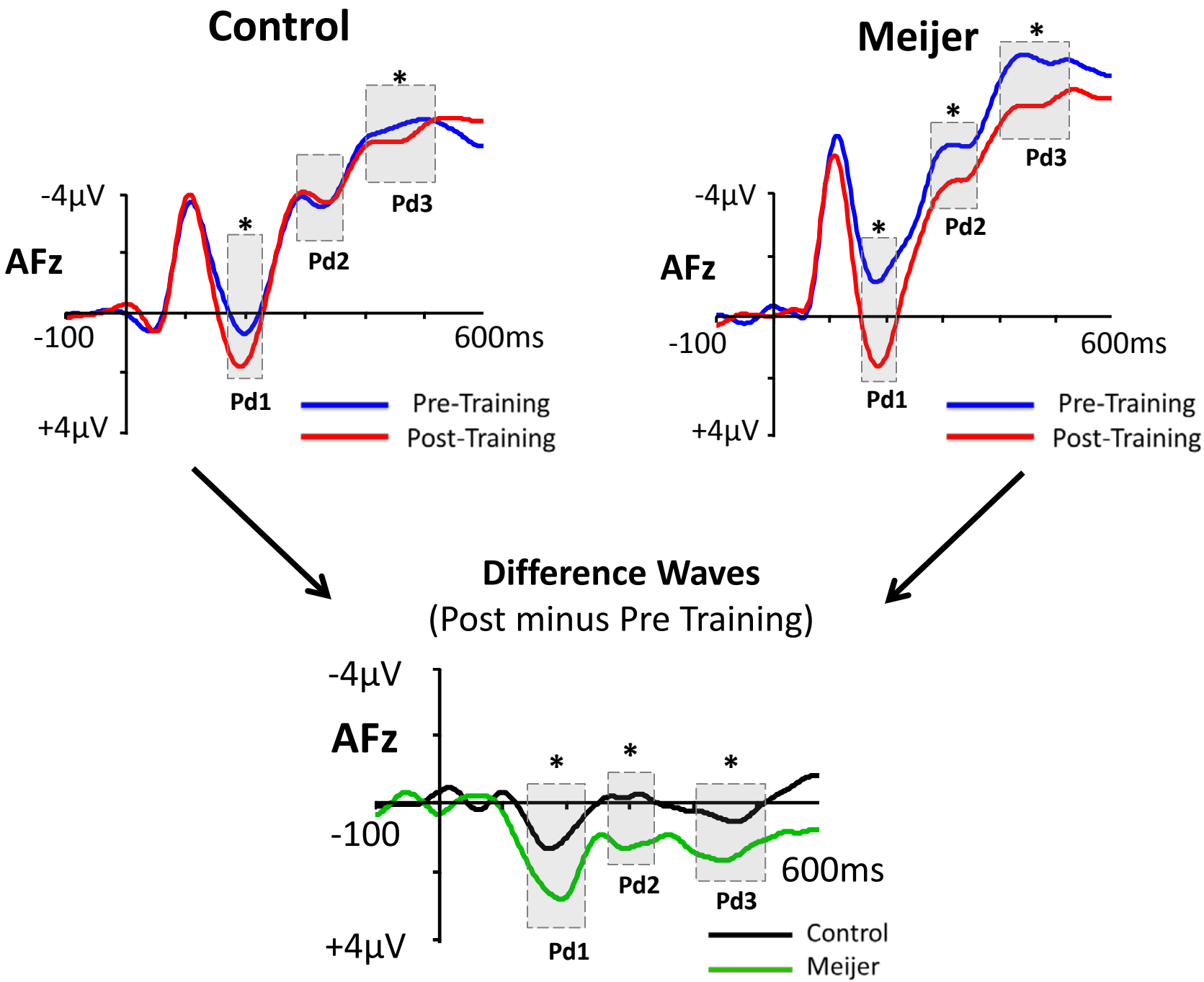


EEG recording

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

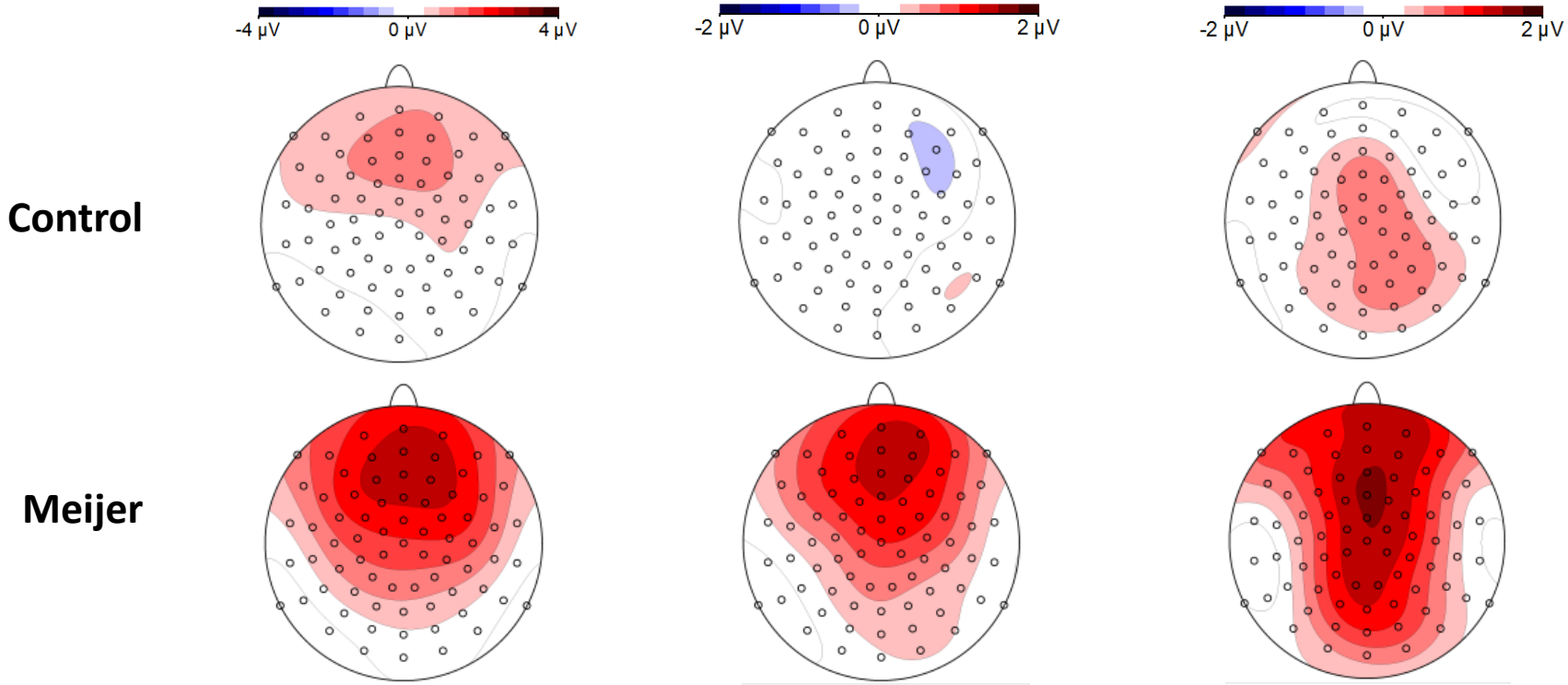
ERP Results
-Auditory-

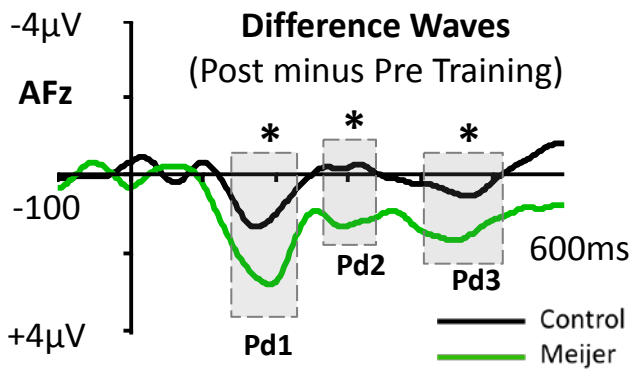



Control
Meijer
AFz
-4µV
+4µV
-100
600ms
Pd1
Pd2
Pd3
*
Pre-Training
Post-Training
Difference Waves
(Post minus Pre Training)
Control
Meijer

Difference Maps
(Post minus Pre Training)

Pd1: 170-210ms **Pd2: 270-310ms** **Pd3: 400-500ms**



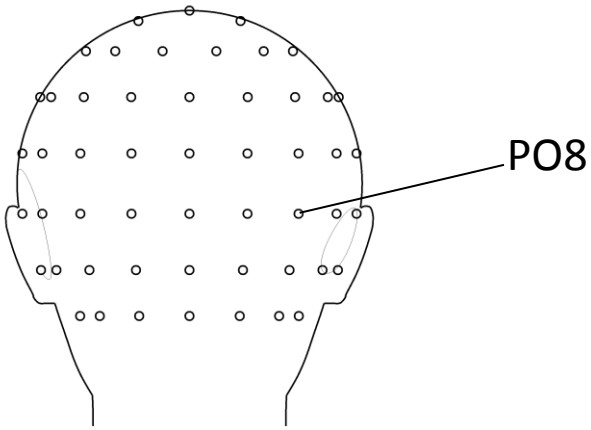


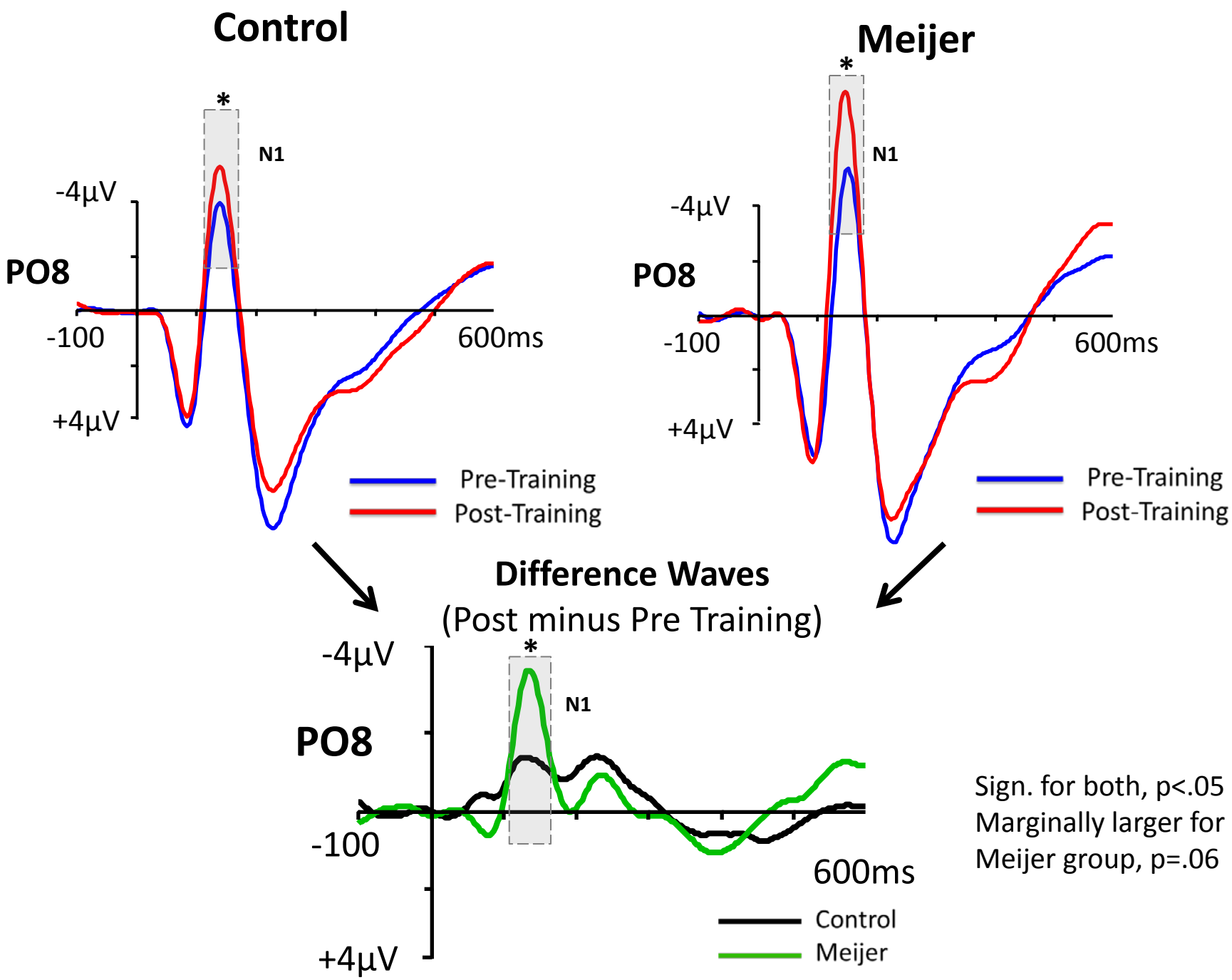
Auditory Results Summary

- Comparing ERPs elicited by sounds before and after training, we found Pd1 and Pd3 changes that were present in both groups. However, they were larger in the Meijer group.

- A Pd2 effect (270-310ms) was observed **only in the Meijer group.**

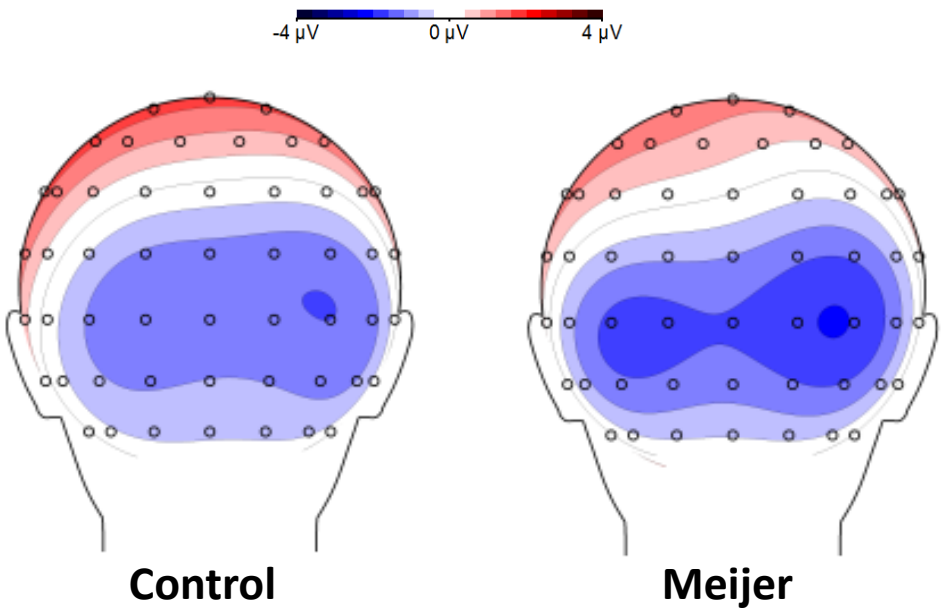
ERP Results
-Visual-

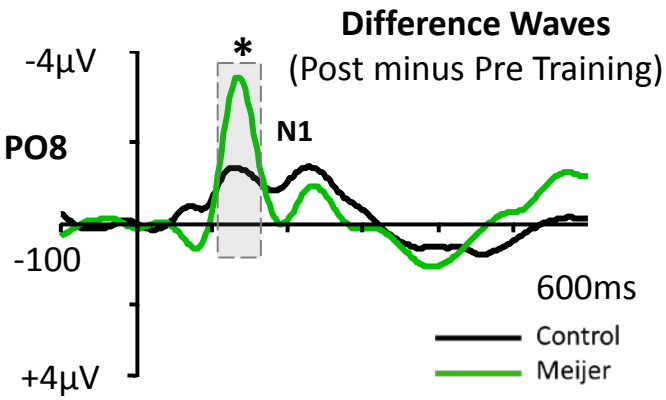



Control
Meijer
*
N1
-4µV
PO8
-100
600ms
+4µV
Pre-Training
Post-Training
Difference Waves
(Post minus Pre Training)
Control
Meijer
Sign. for both, p<.05
Marginally larger for
Meijer group, p=.06

Difference Maps
(Post minus Pre Training)

N1: 110-180ms





Visual Results Summary

- Comparing ERPs elicited by visual images before and after training show a larger N1 (110-180ms) in both groups, but this increase was larger for the Meijer group.

Conclusions

Sensory substitution training enhances changes in electrophysiological activity that come about through cross-modal learning.

Possible neural correlate of (visual-auditory) sensory substitution= auditory P2d (270-310 ms).

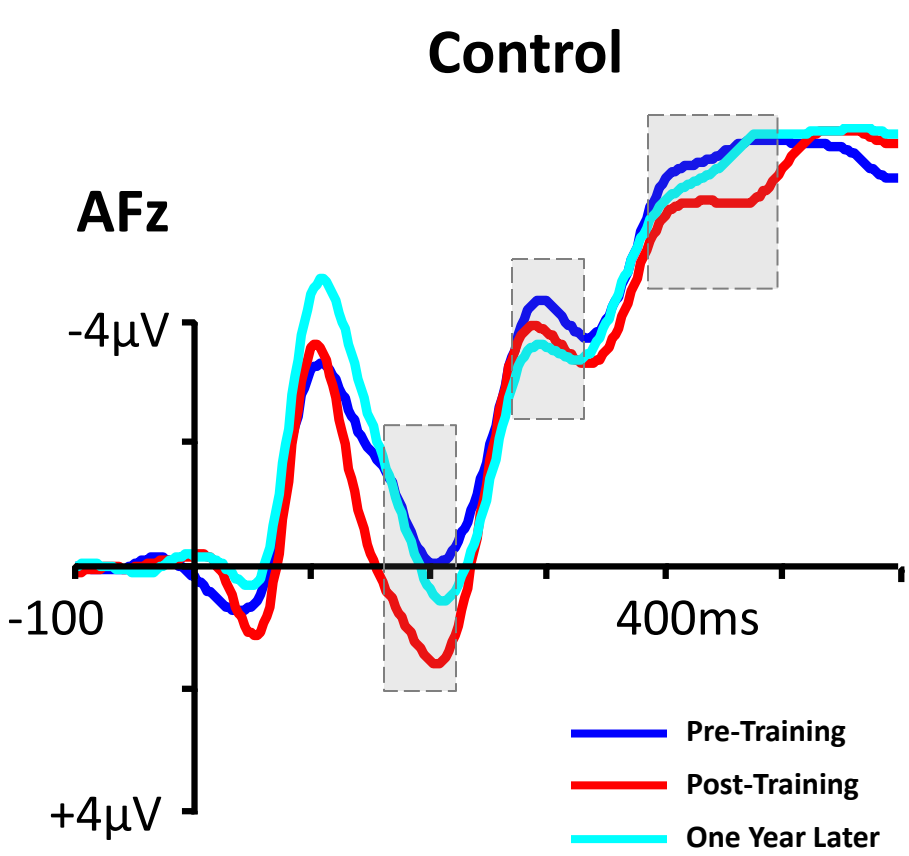
How long does Meijer training last?

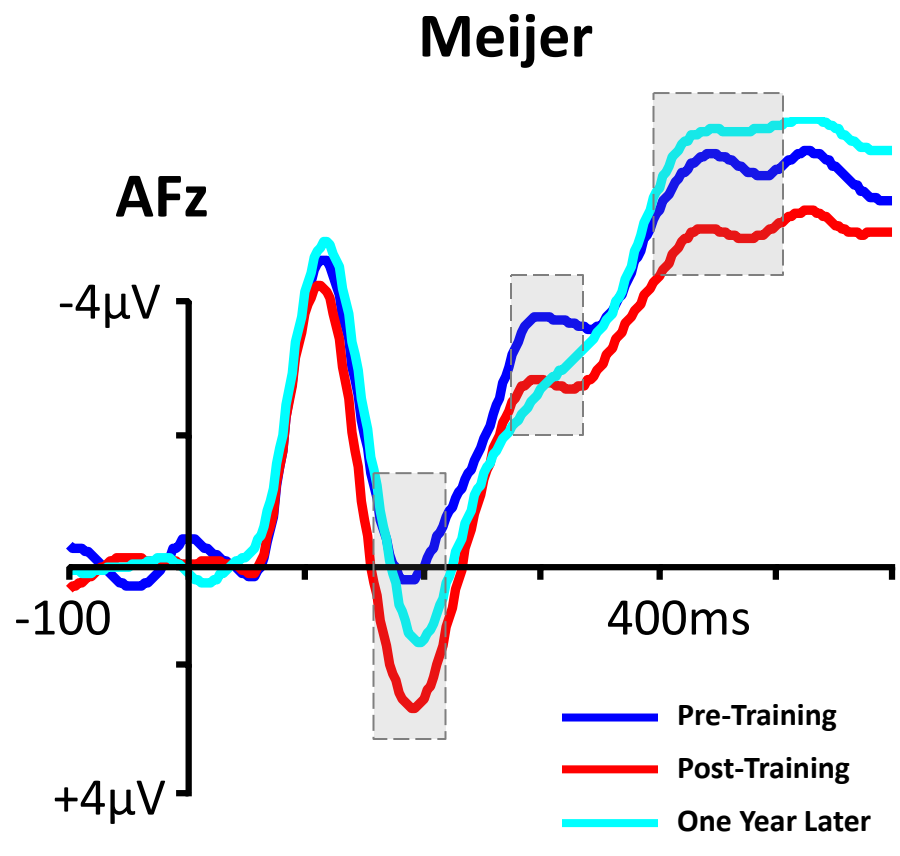
A year later we brought back:

5 participants from the Association group

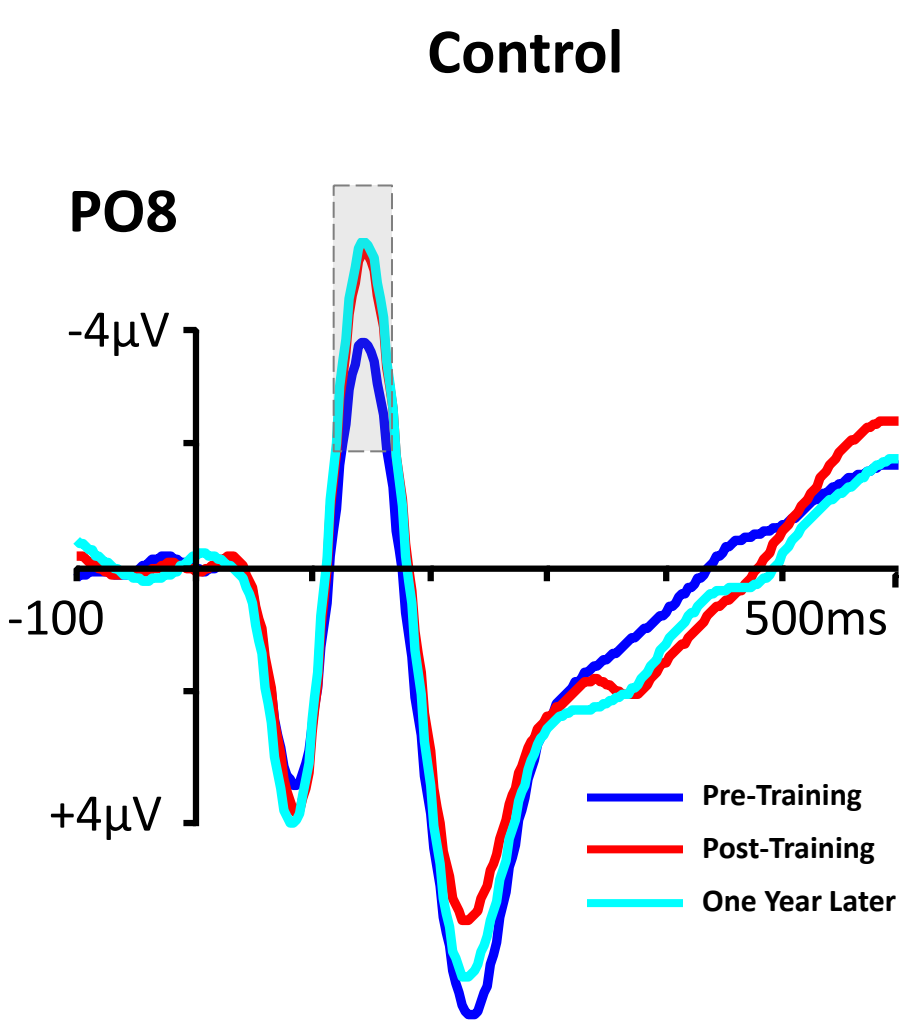
6 participants from the Meijer group

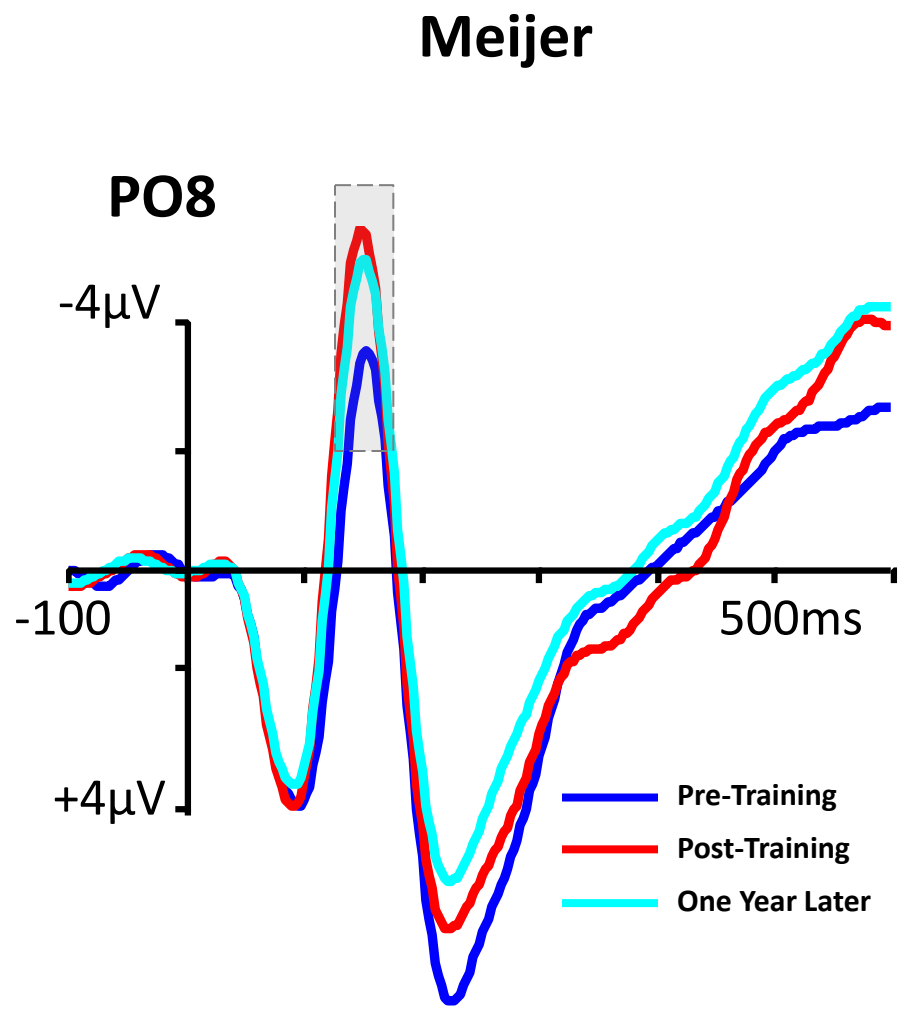
Auditory Data





Visual Data

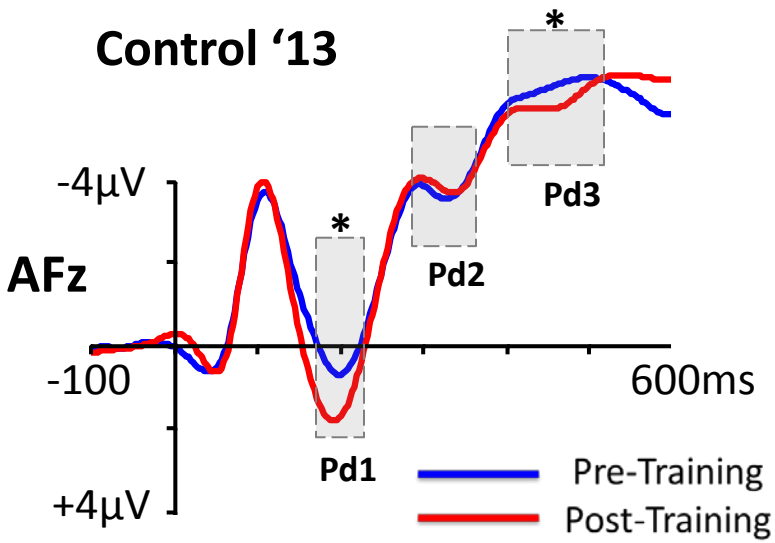

Control
PO8
-4µV
+4µV
-100
500ms
Pre-Training
Post-Training
One Year Later

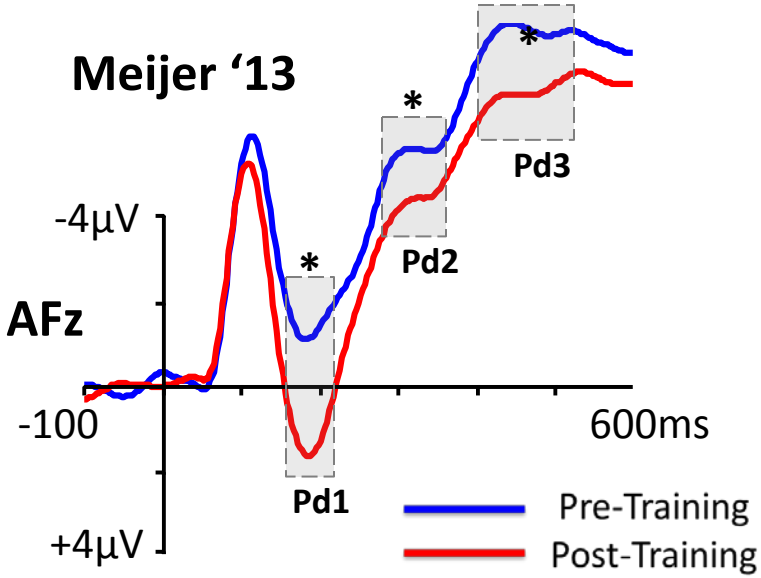

Meijer
PO8
-4µV
+4µV
-100
500ms
Pre-Training
Post-Training
One Year Later

New design, ongoing study (preliminary data)

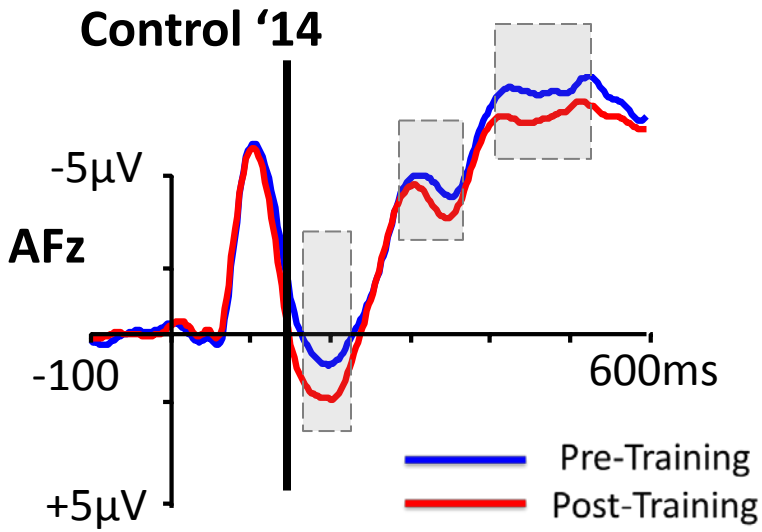
- Equate pre- vs. post-training tasks (uni-modal matches/mismatches).
- Include novel stimuli in pre- and post-training sessions (to control for exposure).
- Replicate our findings.

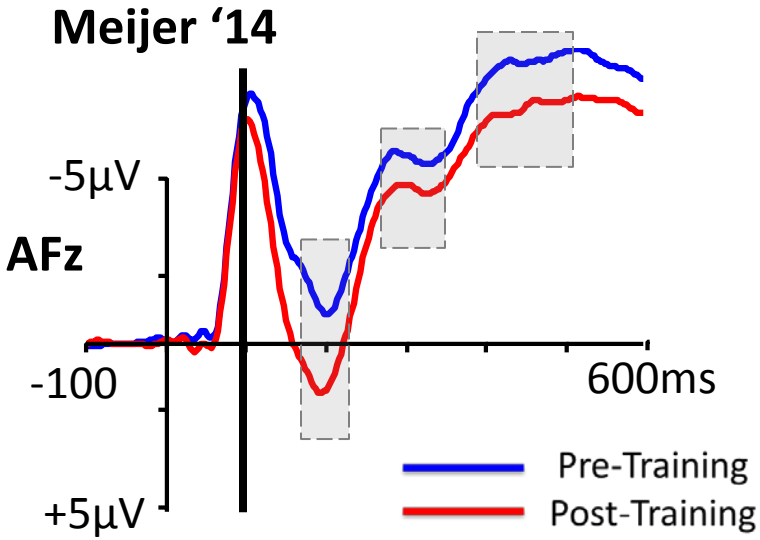
Auditory Data 2013



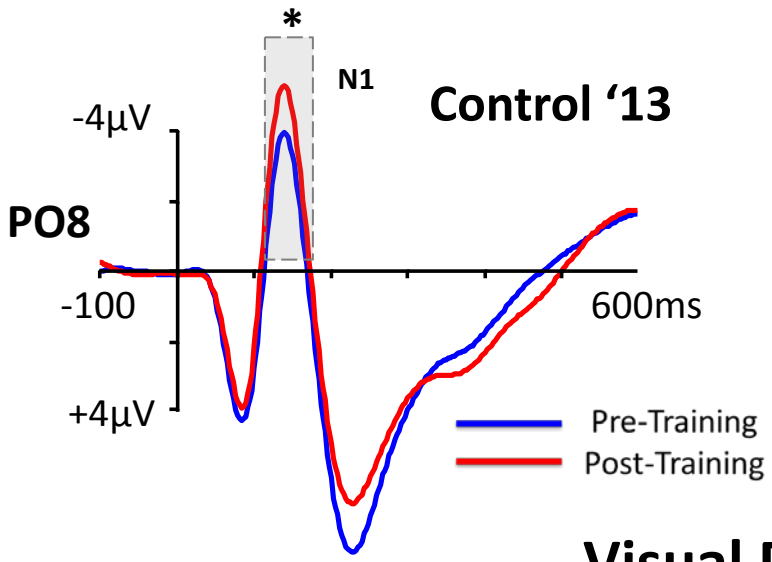


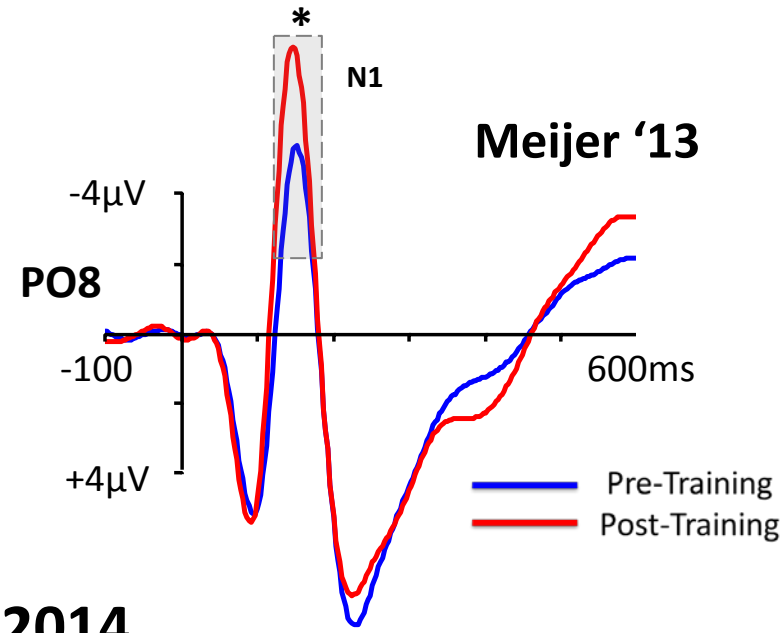
Auditory Data 2014



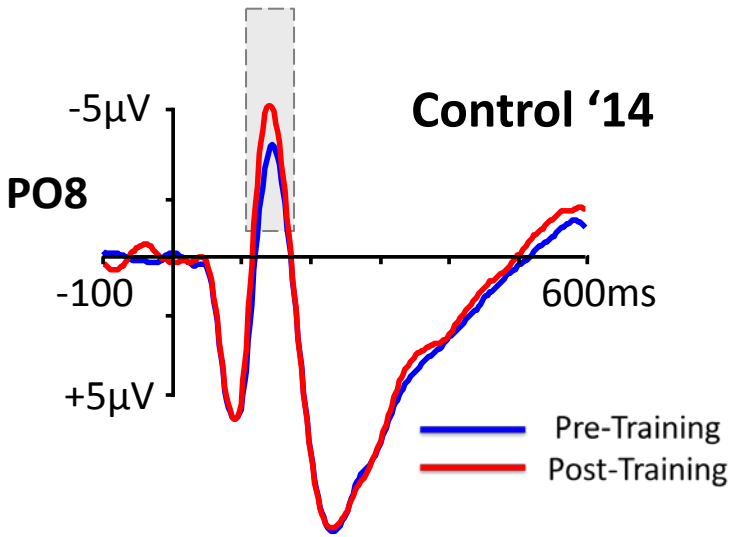


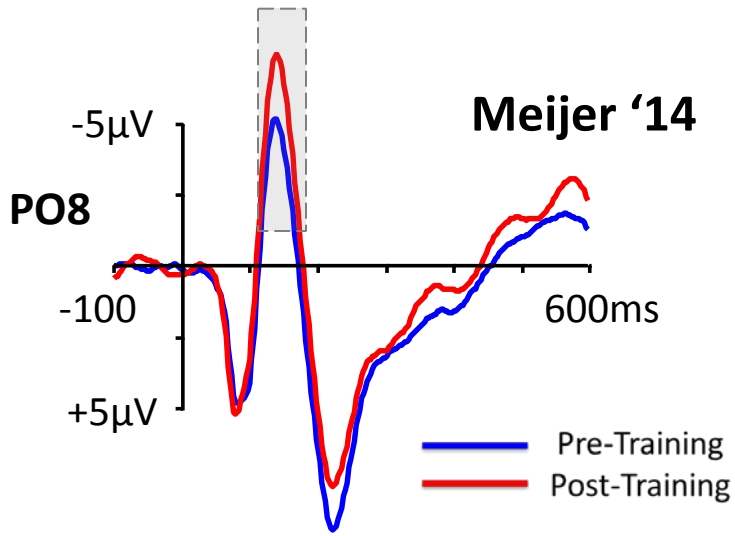
Visual Data 2013





Visual Data 2014





Plans and outstanding questions

- Investigate timing differences (via mass univariate analysis).
- Source analysis
- How similar is this process to that observed in blind individuals?

THANK YOU