

# ERP MEASURES OF ATTENTION AND COGNITIVE CONTROL DURING NEW AUDITORY WM TASKS: PRELIMINARY FINDINGS FOR N1 DIPOLE AMPLITUDE

## Introduction

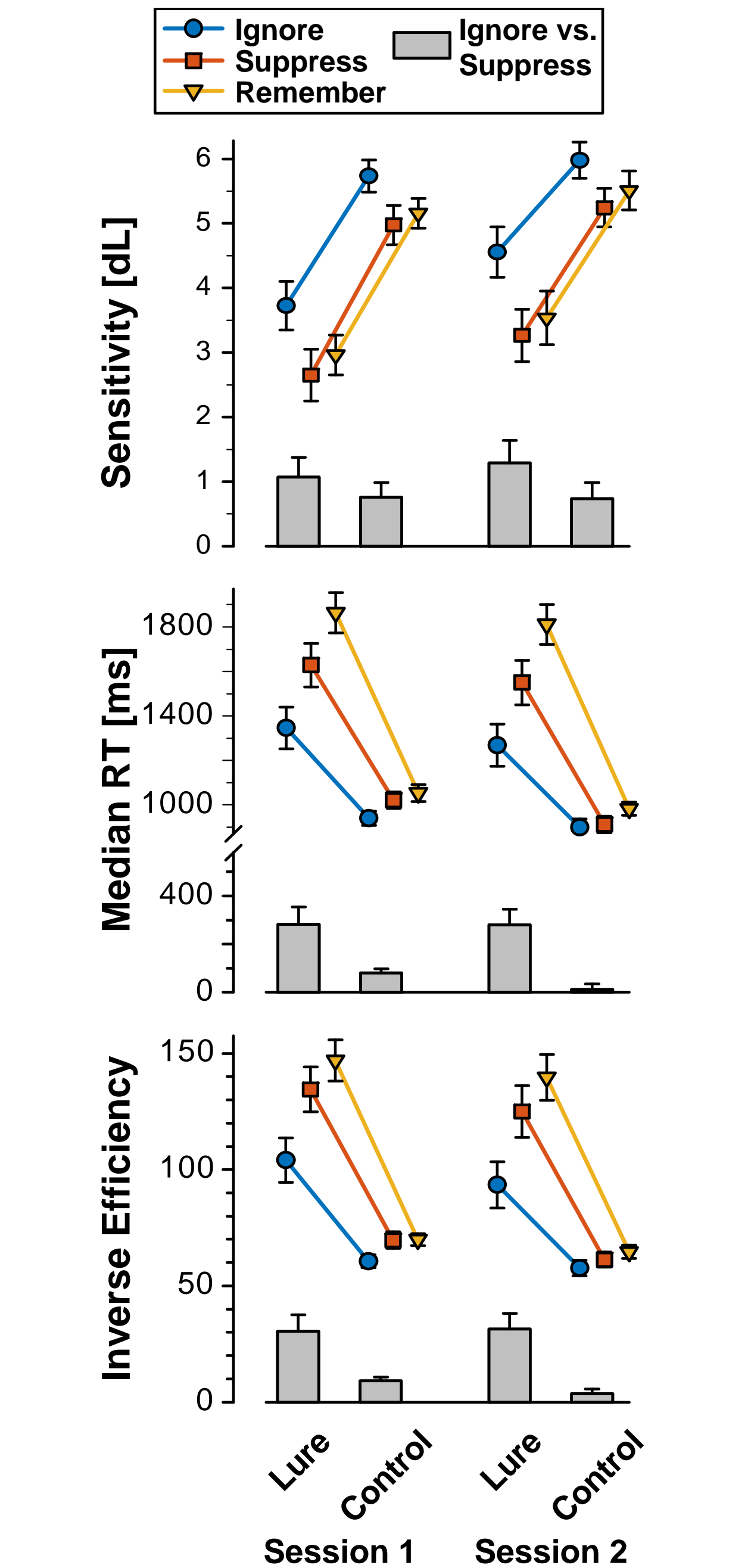
- We developed a new auditory working memory (WM) paradigm (Fig. 1) to dissect the role of perceptual “bottom-up” and “top-down” attention or inhibitory control processes in WM that would be of particular value in studies of cognitive function in schizophrenia<sup>1</sup>
- ERPs were recorded twice (1 week retest) from healthy adults ( $N = 29$ ) during encoding, maintenance, and item retrieval in three auditory WM tasks
- Each task consisted of listening to a series of 4 letters alternately presented to **left ear (LE)** and **right ear (RE)**; 600 ms SOA, followed by a maintenance interval and a probe.
- Participants selectively attended to letters presented to one ear and ignored those in the other ear (**I: Ignore**), suppressed letters presented to one ear (**S: Suppress**), or remembered all letters (**R: Remember**)
- The critical cue was provided either *before* (**I**) or *after* (**S**) the encoding series, or *with the probe* (**R**)
- Here we focus on **monaural** item presentations during the encoding series, which should yield stronger stimulus-related activations of the **contralateral** auditory cortex

## Objective:

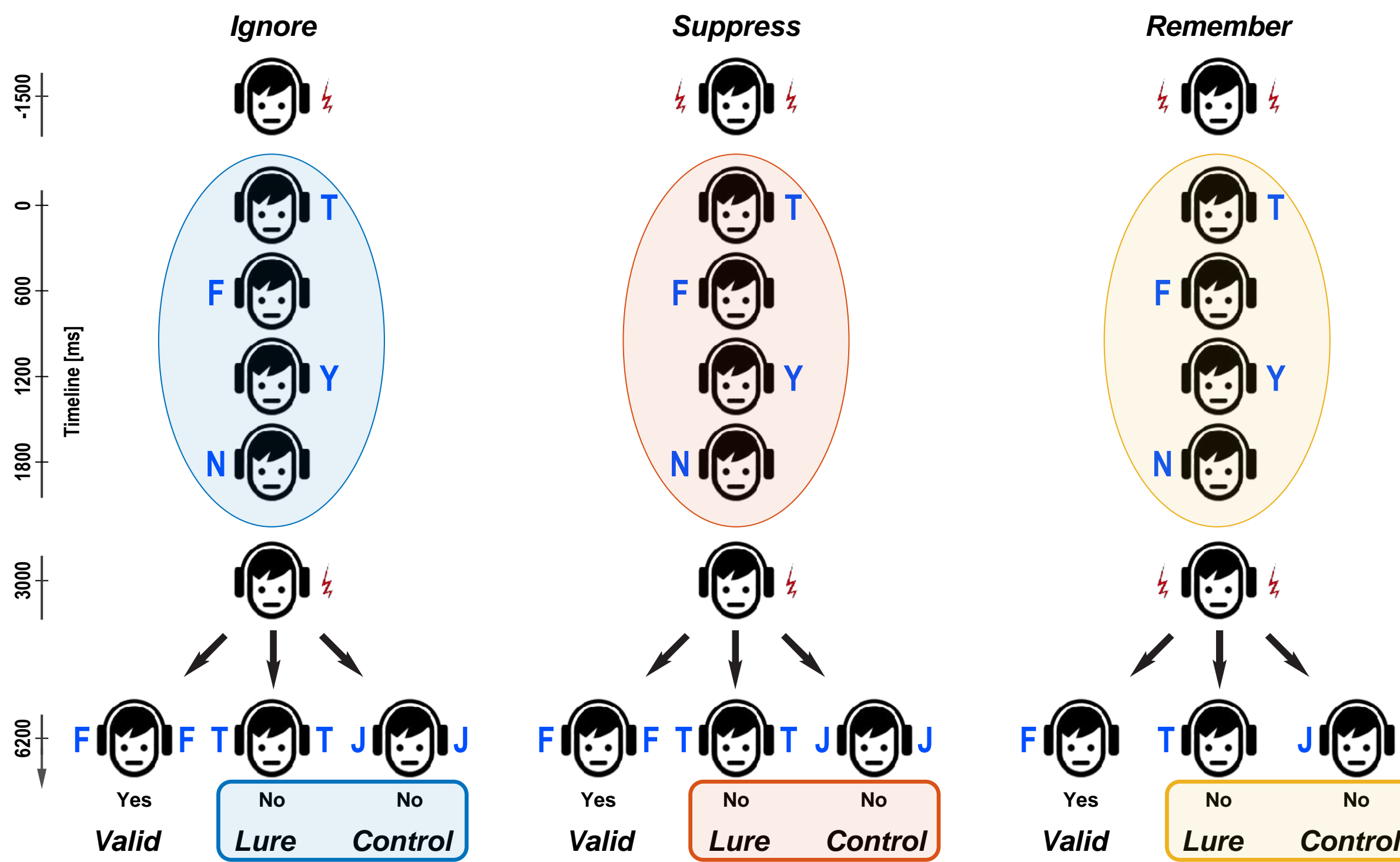
- Examine how mandatory perceptual processes (*bottom-up*: contralateral N1 to speech sounds) are modulated by cognitive control processes (*top-down*: cued attention to prevent letter encoding)
- A **Presentation × Attend** interaction is predicted for **Ignore** but not **Suppress** or **Remember**

## Participants

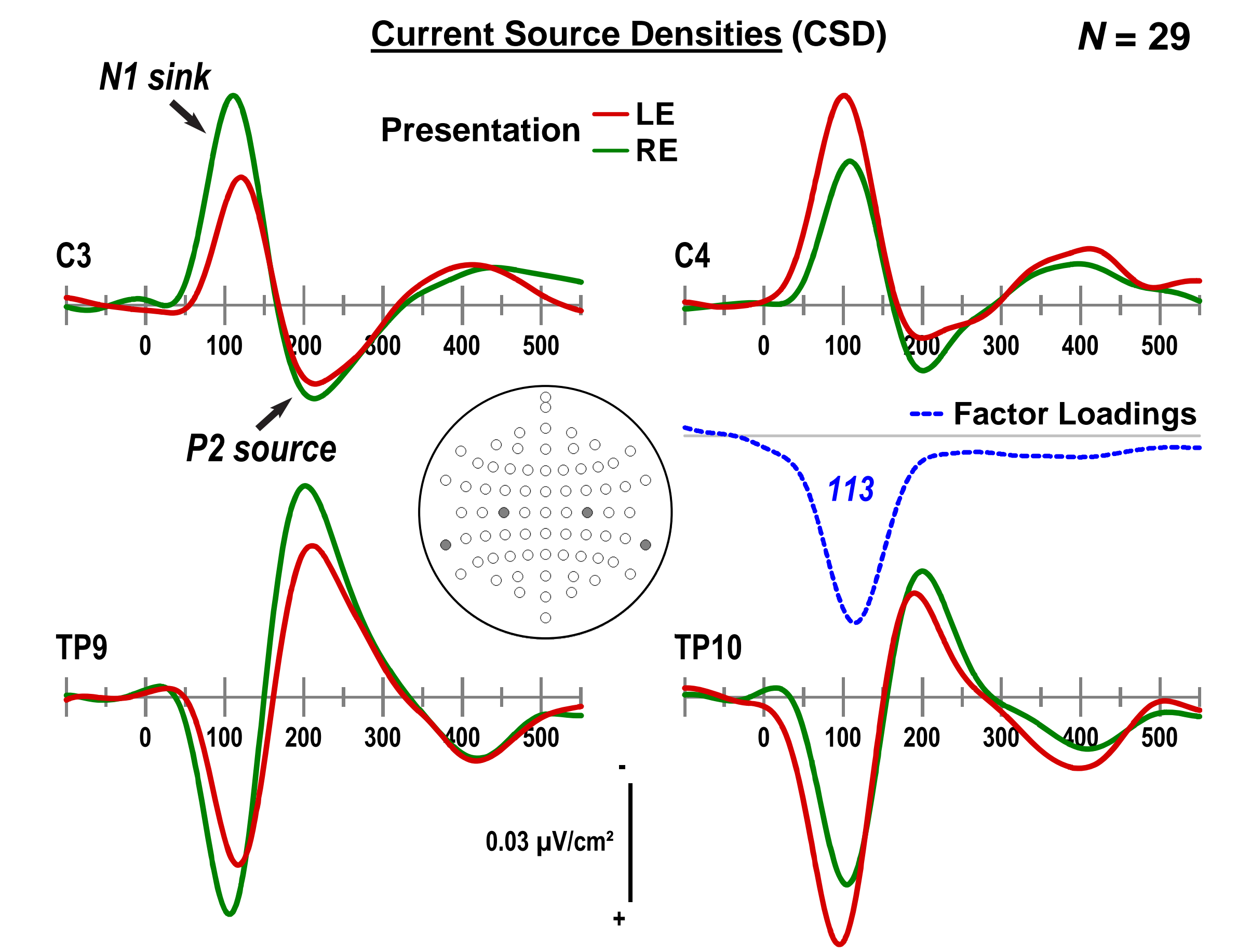
Means (SD) and ranges for core demographics				
Healthy Adults ( $N = 29$ , 13 male)				
Variable	Mean	SD	Min	Max
Age (years)	30.5	10.0	18	55
Education (years)	15.3	2.0	12	19
Handedness (LQ) <sup>13</sup>	81.0	24.2	20.0	100.0



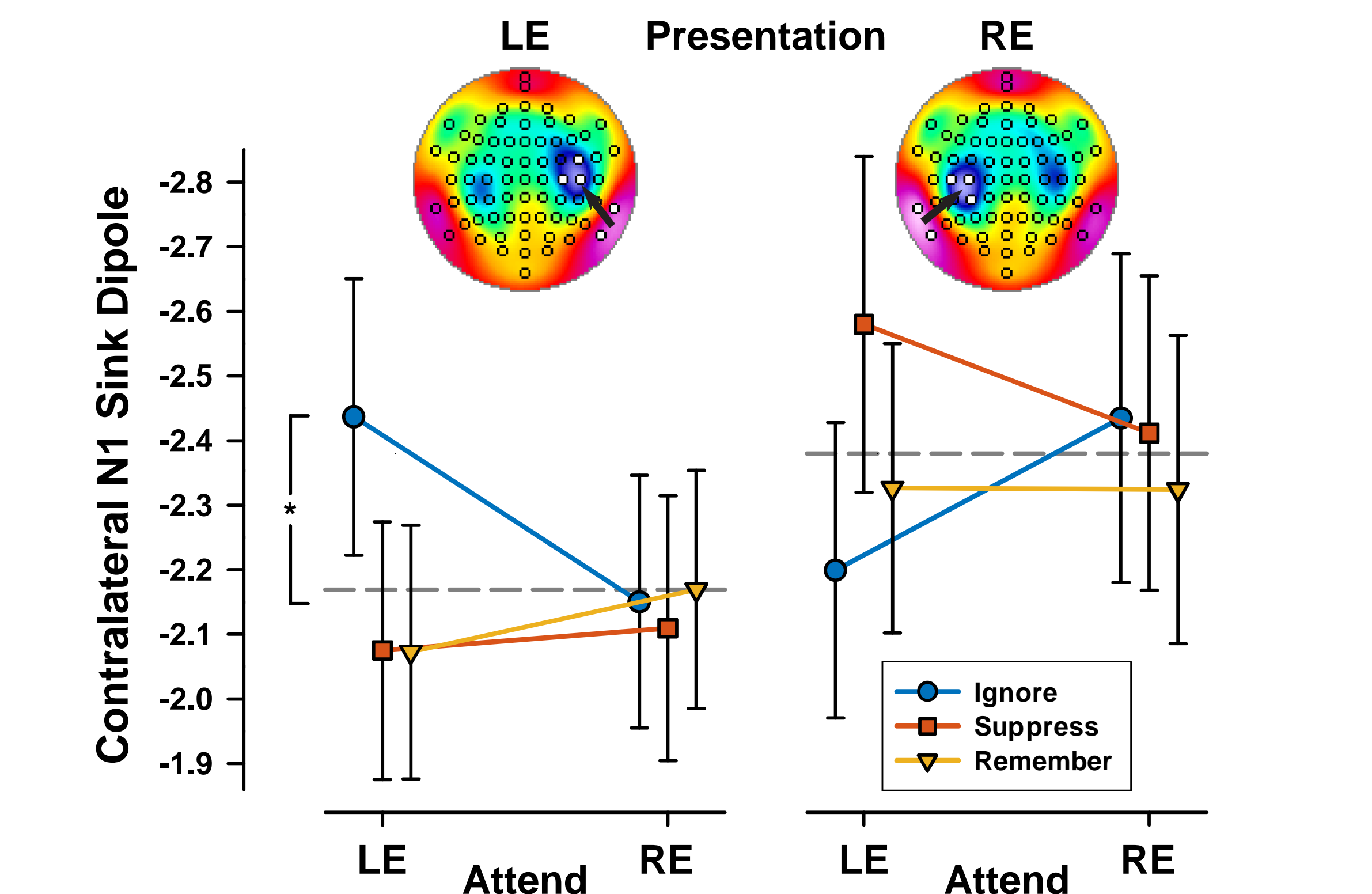
**Fig. 2.** Mean ( $\pm$ SEM)  $d'$ -like sensitivity measure  $d_L$  (no response bias)<sup>16</sup>, median latency to correct responses, and their inverse efficiency:  $RT_{Median}/(d_L + 10)$ . ANOVAs comparing *Ignore* and *Suppress* revealed significant effects of *Task*, *Condition*, *Session*, and *Task × Condition* for all measures (all  $F_{[1,28]} \geq 7.74$ , all  $p \leq .03$ ). The *Suppress* vs. *Remember* comparison yielded *Task × Condition* effects for  $RT_{Median}$  and inverse efficiency (both  $F_{[1,28]} \geq 7.62$ , both  $p \leq .01$ ), demonstrating better performance for *Suppress* than *Remember*. All behavioral measures had **good or excellent internal consistency** in each session ( $.858 \leq$  Cronbach's  $\alpha \leq .919$ ) and **good or excellent temporal stability** across sessions ( $.886 \leq$  Spearman-Brown coefficient  $\leq .974$ ).



**Fig. 1.** Schematic for *Ignore*, *Suppress* and *Remember* tasks.



**Fig. 3.** Grand mean surface Laplacian (CSD) waveforms at selected medial-central (C3/4) and inferior temporoparietal sites (TP9/10) for LE and RE presentations (pooled across sessions, tasks and ear attended). Distinct CSD components included: **N1 sink** (C3 peak latency 110 ms) with a corresponding temporoparietal source (TP9, 109 ms); **P2 source** (C3, 205 ms) with a corresponding temporoparietal sink (TP9, 196 ms). Amplitudes were greater over the contralateral hemisphere. Ipsilateral peak latencies were delayed by 10 ms. **N1 sink** was optimally summarized by the second CSD-tPCA factor (**113** ms, 14.8% explained variance).



**Fig. 5.** Contralateral N1 sink dipole was greater with RE (LH) than LE (RH) presentations (means marked by gray dashes). Significant interactions of *Task × Ear Presented* ( $F_{[2,56]} = 3.45$ ,  $p = .04$ ,  $\epsilon = .993$ ) and *Task × Ear Presented × Ear Attended* ( $F_{[2,56]} = 4.73$ ,  $p = .02$ ,  $\epsilon = .903$ ) originated from **Ignore** (*Ear Presented × Ear Attended*,  $F_{[1,28]} = 9.84$ ,  $p = .004$ ) and **LE attended** (*Task × Ear Presented*,  $F_{[2,56]} = 6.92$ ,  $p = .002$ ,  $\epsilon = .983$ ), with a simple main effect of *Ear Attended* at *Ignore/LE Presented* ( $F_{[1,28]} = 4.25$ ,  $p \leq .05$ ). Thus, task-related modulations were seen for **Ignore** only, with a relative **increase** for **LE Presented/LE Attended** but **decrease** for **RE Presented/LE Attended**, implying RH-mediated cognitive control (i.e., *top-down*) processes.

**References**  
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<sup>3</sup> Eich TS, et al 2014 *Biol Psychiatry* 76: 146-53  
<sup>4</sup> Hugdahl K 1988 *Handbook of Dichotic Listening*: Bryden MP, pp 1-43; Bradshaw JL, Nettleton N, pp. 45-69  
<sup>5</sup> Kayser J, Tenke CE 2003 *Clin Neurophysiol* 114: 2307-25  
<sup>6</sup> Kayser J, Tenke CE 2006a *Clin Neurophysiol* 117: 348-68  
<sup>7</sup> Kayser J, Tenke CE 2006b *Clin Neurophysiol* 117: 369-80  
<sup>8</sup> Kayser J, Tenke CE 2015 *Int J Psychophysiol* 97: 189-209  
<sup>9</sup> Kayser J, et al 2006 *Psychophysiology* 43: 237-52  
<sup>10</sup> Kayser J, et al 2010 *Psychophysiology* 47: 1075-86  
<sup>11</sup> Nee DE, Jonides J 2008 *Proc Natl Acad Sci USA* 105: 14228-33  
<sup>12</sup> Nee DE, Jonides J 2009 *Neuroimage* 45: 963-75  
<sup>13</sup> Oldfield RC 1971 *Neuropsychologia* 9: 97-113  
<sup>14</sup> Perrin F, et al 1989 *EEG Clin Neurophysiol* 72: 184-7

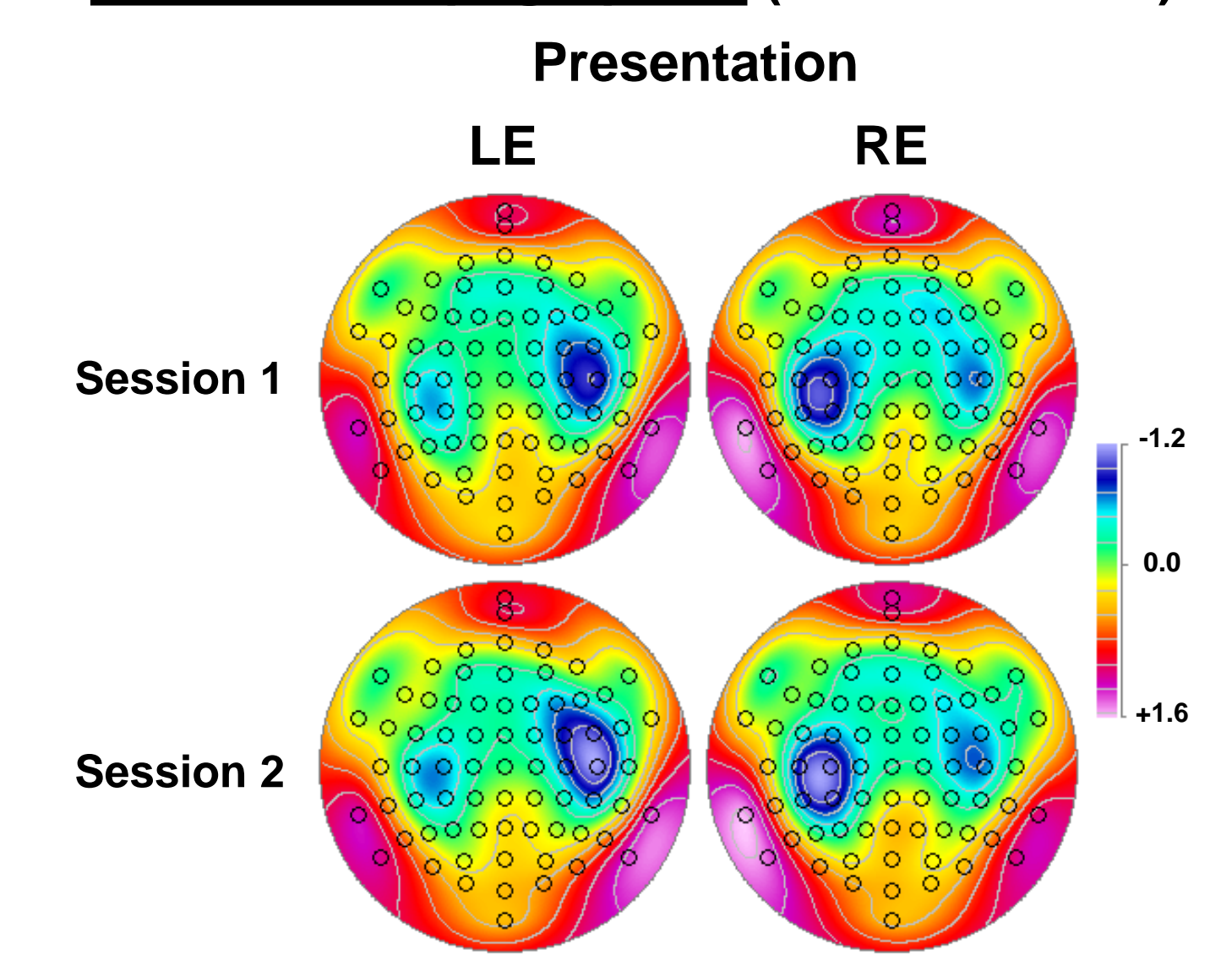
## Ignore/Suppress Auditory Working Memory (AWM) Tasks

- Auditory analogs of **visual Ignore/Suppress** tests<sup>12-13</sup>, which manipulate interference control during WM<sup>3,15</sup>, were supplemented by a Sternberg-like **Remember** WM tests designed as a **Suppress** control condition
- WM tests combine advantages of serial position<sup>9</sup> and dichotic listening tasks<sup>4</sup>
- Encoding, maintenance and retrieval phases (item/cue sequence) are virtually identical for *Ignore*, *Suppress*, and *Remember* tasks
- Design prevents information from entering into WM (*Ignore*), removes encoded information from WM (*Suppress*), or keeps all information in WM (*Remember*)
- Comparison of accuracy and RT for negative responses to *Lure* and *Control* (each 30% of all trials) provides a behavioral index of cognitive control
- Perfectly selecting only letters on the attended or remembered side would produce no performance difference for lures and controls; if selection is poor, the difference between them will be large

## EEG/ERP Recording and Analysis

- 72-channel EEG (nose reference)
- Biosemi, DC-51.3 Hz, 1024 samples/s
- spatial SVD blink reduction (continuous EEG)
- 750 ms epochs (178 ms pre-stimulus)
- ERP averages (artifact-free trials) low pass filtered at 12.5 Hz (-24 dB/oct), 100 ms baseline correction
- reference-free current source densities (CSD) (spherical splines surface Laplacian<sup>8,14,17</sup>) computed for each ERP (sharpen topographies, eliminate volume-conducted activity)
- CSD-tPCA: CSD-transformed ERPs submitted to **unrestricted temporal principal components analysis (tPCA)** [769 variables = stimulus-locked samples -178 to 572 ms; 50112 observations = 29 Subjects x 2 Sessions x 72 Sites x 12 Conditions (Task: Ignore/Suppress/Remember x Ear Attended: LE/RE x Ear Presented: LE/RE)], followed by Varimax rotation of covariance loadings<sup>5-7</sup>
- identify and measure neuronal generator patterns underlying auditory N1 (**N1 sink**, primary auditory cortex) with meaningful, high-variance CSD factor previously identified<sup>6-8,17</sup>
- submit factor scores corresponding to **contralateral N1 sink dipole amplitude** to repeated measures ANOVA with *Session* (1, 2), *Task* (Ignore, Suppress, Remember), *Ear Presented* (LE/RH, RE/LH) and *Ear Attended* (LE/RH, RE/LH) as within-subjects factors

## CSD-tPCA Topographies (Factor Scores)



**Fig. 4.** Grand mean **N1 sink** topographies (factor 113) for LE and RE presentations in each test session (pooled across tasks and ear attended). As expected, a distinct sink-source N1 dipole pattern spanning primary auditory cortex (Sylvian fissure) over each hemisphere was more robust over the contralateral hemisphere (Ear Presented x Hemisphere,  $F_{[1,28]} = 23.9$ ,  $p < .0001$ ). **Contralateral N1 dipole amplitude** was quantified as the difference between the central sink and the corresponding inferior-parietal source.

**Contralateral N1 dipole amplitude** showed **excellent internal consistency** in each session (Cronbach's  $\alpha = .958$  and  $.959$ ) and **excellent test-retest reliability** across sessions (Spearman-Brown coefficient =  $.927$ ).

## Conclusions

- Monaural presentations of speech sounds (letters) yield a robust asymmetric activation of primary auditory cortex, as revealed by enhanced contralateral N1 sink dipole amplitudes (**Figs. 3-4**)
- These stimulus-driven (*bottom-up*) perceptual asymmetries show excellent reliabilities (internal consistency and stability over 1 week; **Fig. 4**)
- While *attending to LE* (RH) during *Ignore*, the contralateral N1 dipole was **enhanced** with LE and **reduced** with RE presentations; these modulations were not seen when attending to RE (LH), or for *Suppress* and *Remember* tasks (**Fig. 5**)
- These findings suggest that early *top-down* modulation of perceptual *bottom-up* asymmetries during auditory stimulus encoding into WM are primarily under control of a right-lateralized attention network<sup>2</sup>