Transcranial Direct Current Stimulation of the Superior Parietal Cortex Modulates Reference Processing during Reading Comprehension

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Introduction. Reference tracking is the ability to keep up with who or what is being referred to across sentences. The repeated name penalty (RNP) is the cognitive processing delay caused by the use of a repeated name in situations where a pronoun would suffice (Gordon et al., 1993). For example, sentences with repeated names (e.g., *Bill*) are read slower than sentences with a pronoun (e.g., *he*) when referring to a previously mentioned salient referent (Almor & Nair, 2007; Gordon et al., 1993). MRI studies have found that the RNP is associated with bilateral activation in the superior parietal cortex (SPC), a brain region recruited during spatial tracking of visual stimuli (e.g., Conder et al., 2017). This suggests that the SPC is involved in consolidating multiple linguistic references. However, neurolinguistic models of sentence processing rarely include these parietal regions, highlighting instead the left inferior frontal gyrus (IFG) as a core node in the syntactic network (e.g., Den Ouden et al., 2012). To test whether either area plays a causal role in the RNP, we compared the effect of cathodal high-definition transcranial direct current stimulation (HD-tDCS) to the two areas on the RNP.

Method. 85 right-handed native English speakers with normal/corrected-to-normal vision and no language disorders participated; 14 were excluded due to missing data or self-reported absence of stimulation sensation. The study had a 2x2x2x3 factorial design, with three within-participant factors: block (online stimulation, post-stimulation), reference form (name, pronoun) and antecedent salience (salient, non-salient); and one between-participant factor: stimulation type (left IFG, bilateral SPC, Sham). In the IFG and SPC conditions, stimulation of -2 milliamps was applied for 20 minutes; in the Sham condition, stimulation only occurred during the first and final minute. The self-paced reading task (sentence-by-sentence presentation) included 96 three-sentence discourses followed by yes/no comprehension questions; the third sentence was manipulated for reference form and antecedent salience (see example stimuli in appendix). Half of the critical trials were completed while receiving stimulation (online stimulation block); the remaining critical trials followed stimulation (post-stimulation block).

Results. Log transformed reading times (log RTs) of the third sentences were analyzed using linear mixed-effects models. A significant interaction between reference form and antecedent salience confirmed the presence of the RNP (β = -.022, SE = .005, t = -4.151, p < .0001). There was also a 3-way interaction for stimulation block, reference form, and antecedent salience approaching significance, β = .01, SE = .005, t = 1.948, p = .052, suggesting that the RNP was modulated by cathodal stimulation. See Table 1 for selected regression results. Post-hoc comparisons further revealed that cathodal stimulation affected the RNP only in the SPC condition, $X^2(1) = 4.14$, p < .05, but not in the IFG and Sham conditions, p's > .65.

Conclusion. Application of cathodal HD-tDCS to the bilateral SPC region modulated the RNP during a self-paced reading task. No such effects were found in the left IFG condition or the Sham condition. These results show, for the first time, that the bilateral SPC plays a *causal* role in the RNP, suggesting that parietal regions not typically associated with language are indeed important for reference tracking (as gauged by the RNP). As such, these results support previous theories that were so far only supported by imaging results which do not necessarily implicate causality (Boiteau et al., 2017; Conder et al., 2017). The involvement of the bilateral SPC suggests that spatial mechanisms are involved in reference tracking. This is compatible with the looking-at-nothing phenomenon, wherein people use integrated visual and linguistic representations during information retrieval (e.g., Ferreira et al., 2008), as well as the use of spatial indices for references in sign languages (Emmorey, 2001). We conclude that reference tracking relies on visuospatial regions in the parietal region. We propose that models of language comprehension which address discourse should include the parietal region as central to reference processing.

References:

Almor, A. & Nair, V. A. (2007). The form of referential expressions in discourse. *Language and Linguistics Compass,* 1 (1-2), 84–99. https://doi.org/10.1111/j.1749-818X.2007.00009.x

Boiteau, T. W., Smith, C. M., & Almor, A. (2017). Syntax response-space biases for hands, not feet. *Attention, Perception, & Psychophysics,* 79(3): 989–999. DOI: 10.3758/s13414-016-1271-8

Conder, J., Fridriksson, J. Baylis, G., Smith, C., Boiteau, T. W., & Almor, A. (2017). Bilateral parietal contributions to spatial language. *Brain and Language*, 164, 16-24. https://doi.org/10.1016/j.bandl.2016.09.007

Den Ouden, D.B., Saur, D., Mader, W., Schelter, B., Lukic, S., Wali, E., Timmer, J. & Thompson, C.K. (2012). Network modulation during complex syntactic processing. *Neuroimage*, 59(1), 815-823. https://doi.org/10.1016/j.neuroimage.2011.07.057

Emmorey, K. (2001). *Language, cognition, and the brain: Insights from sign language research*. Psychology Press. https://doi.org/10.4324/9781410603982

Ferreira, F., Apel, J., & Henderson, J. M. (2008). Taking a new look at looking at nothing. *Trends in Cognitive Sciences*, *12*(11), 405-410. https://doi.org/10.1016/j.tics.2008.07.007

Gordon, P. C., B. J. Grosz, & L. A. Gilliom. (1993). Pronouns, names, and the centering of attention in discourse. *Cognitive Science 17(3).* 311–47.

Example stimuli:

Sentence 1: Ed moved into an apartment with Brooke.

Sentence 2: He brought most of the furniture.

Sentence 3 conditions:

	Name	**Pronoun**
Salient	Ed liked having a roommate to help out.	He liked having a roommate to help out.
Non-salient	Brooke liked having a roommate to help out.	She liked having a roommate to help out.

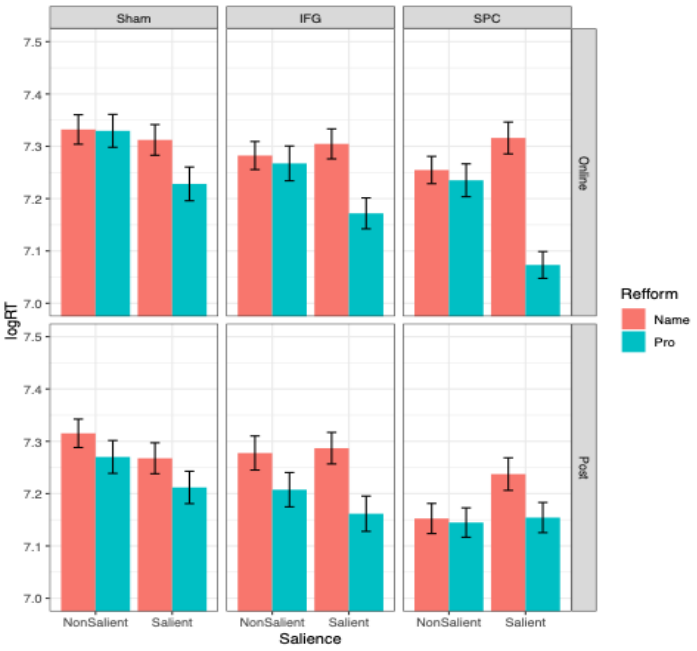

Figure 1 (right): Log RTs for stimulation block, stimulation group, reference form, and salience.

Table 1: Selected model of the effects of reference form, salience, and stimulation group on log RTs (selected coefficients)

	Estimate	***SE***	***df***	***t***	***p***
Intercept	7.24	0.04	112.1	192.65	0.00
Block	-0.03	0.01	39.62	-3.95	0.00
SPC group	-0.00	0.04	70.73	-0.06	0.96
IFG group	0.05	0.04	70.76	1.18	0.24
Salience	0.01	0.01	2718	2.57	0.01
Reference Form	0.04	0.01	2712	6.92	0.00
Salience * Reference Form	-0.02	0.01	2703	-4.15	0.00
Block * SPC group * Salience	-0.01	0.01	2736	-1.67	0.09
Block * Salience * Reference Form	0.01	0.01	2701	1.95	0.05
Number of observations: 2905, Subject (71); Item (48)					