The Neural Circuitry Underlying the "Rhythm Effect" in Stuttering

Saul A. Frankford[1], Shanqing Cai[2], Jason A. Tourville[1], Alfonso Nieto-Castañón[1], Matthew Masapollo[1], Elizabeth S. Heller Murray[1], Frank H. Guenther[1,3,4]

[1]Department of Speech, Language, and Hearing Sciences, Boston University, [2]Google, Inc., [3]Department of Biomedical Engineering, Boston University [4]Department of Radiology, Massachusetts General Hospital

Background

- Stuttering may result from a reduced ability to generate properly timed motor commands [1].
- External isochronous timing cues can reduce or alleviate disfluencies in adults who stutter (AWS) – often termed the **"rhythm effect"** [2].
- Prior neuroimaging studies show that speaking along with a metronome increases activation in auditory, premotor, and basal ganglia structures, potentially normalizing under-activation in these regions [3].
- Stuttering and speech timing are mediated by *brain networks,* so task-based functional connectivity could reveal network changes that lead to fluency.
- Here, we characterize the functional activation patterns and neural connections associated with rhythm-induced fluency in AWS.

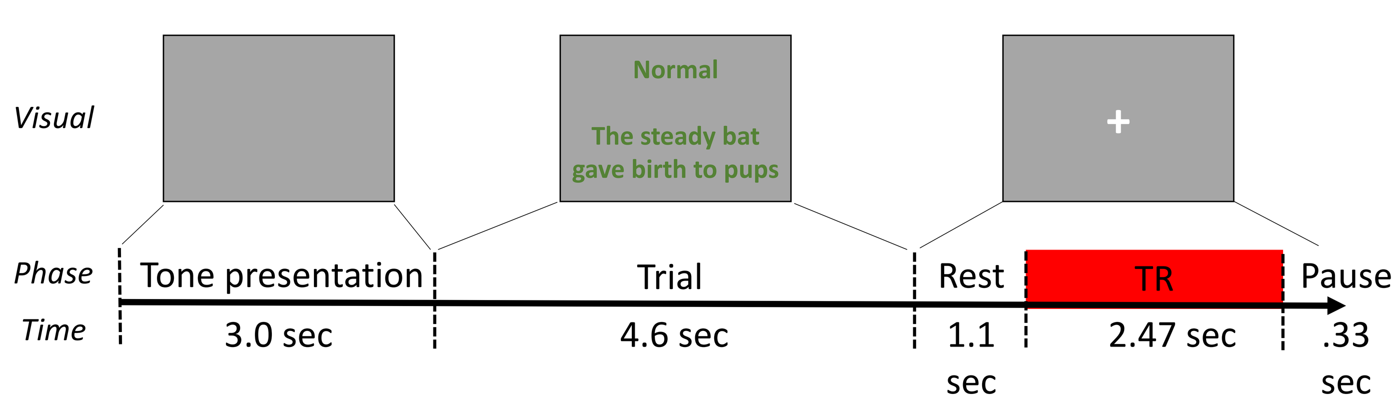
Methods

Subjects: 16 AWS (5 female/11 male, mean age = 29.9 years) and 17 ANS (6 female/11 male, mean age = 28.7 years

Task Paradigm:

- Subject read short sentences aloud during sparse-sampled fMRI
- On each trial, participants heard eight isochronous tones before seeing a cue two speech in one of two conditions – '*rhythm*' or '*normal*' (Figure 1)
- **'*Rhythm*' condition:** produce sentence at the same speed as the tones, aligning each syllable to a beat
- '***Normal***' **condition:** read the sentence using natural stress and pacing
- Trials randomly ordered and interspersed with a silent baseline task

Figure 1. Trial Timing



Acoustic Analyses:

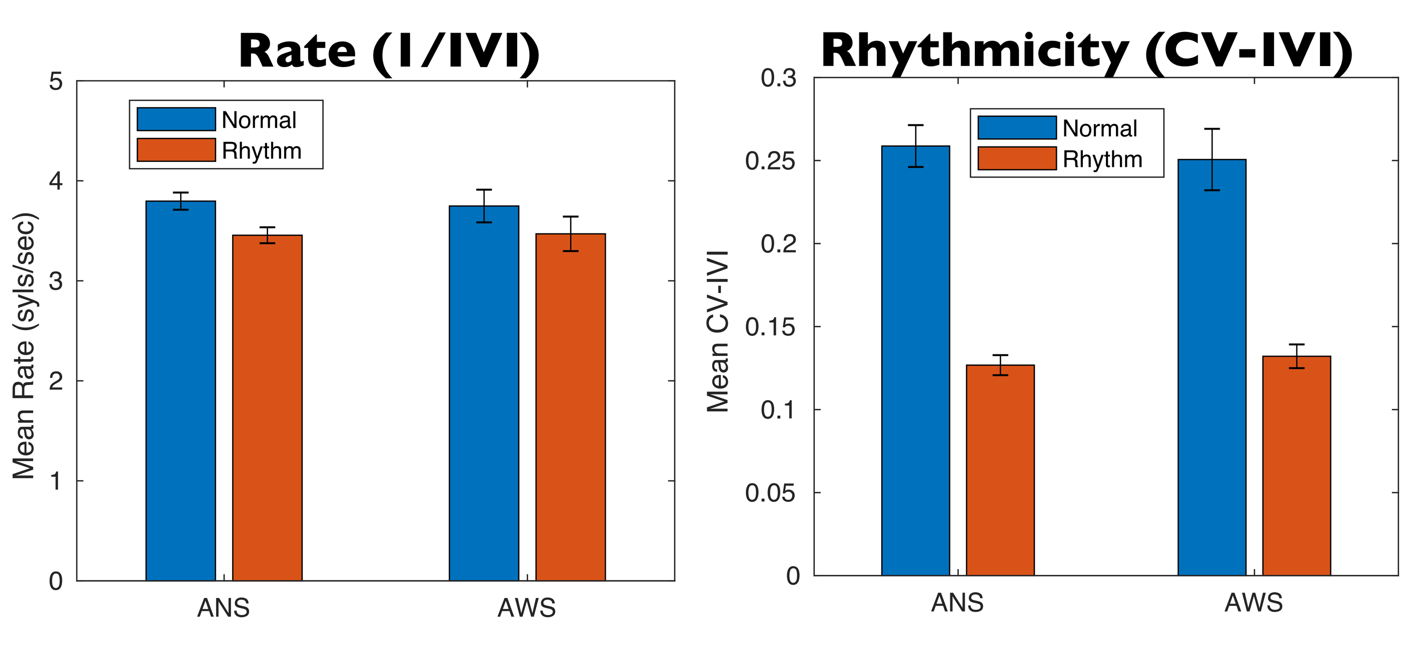
- Speech utterances were analyzed offline to extract speech rate, rhythmicity, and number of disfluent trials

Image data Analyses:

- Functional data were motion-corrected and co-registered to a high-resolution T1-weighted structural image
- Mean activation for each condition was estimated at the level of the vertex (cortical) or voxel (subcortical), controlling for mean **intervocalic interval (IVI)**
- Within and between-group and ***condition effects*** were evaluated using a vertex/voxel-level threshold of p < 0.01 and a cluster-level threshold of p-FWE < 0.05
- ROIs with significant speech activation during either speaking condition or the contrast between conditions (see Figure 1B) were used as seeds for ***functional connectivity analyses***
- ***ROI-to-voxel functional connectivity*** was compared across tasks and groups using a generalized psychophysiological interaction (gPPI) analysis [4], with Bonferroni-corrected cluster-level p-FDR < 0.05

Results

Figure 2. Rate and Rhythmicity



- Both groups spoke significantly slower during the *rhythm* condition. Thus, rate was added as a covariate for neuroimaging analyses
- Groups were significantly more isochronous (i.e., lower CV-IVI) during the *rhythm* condition

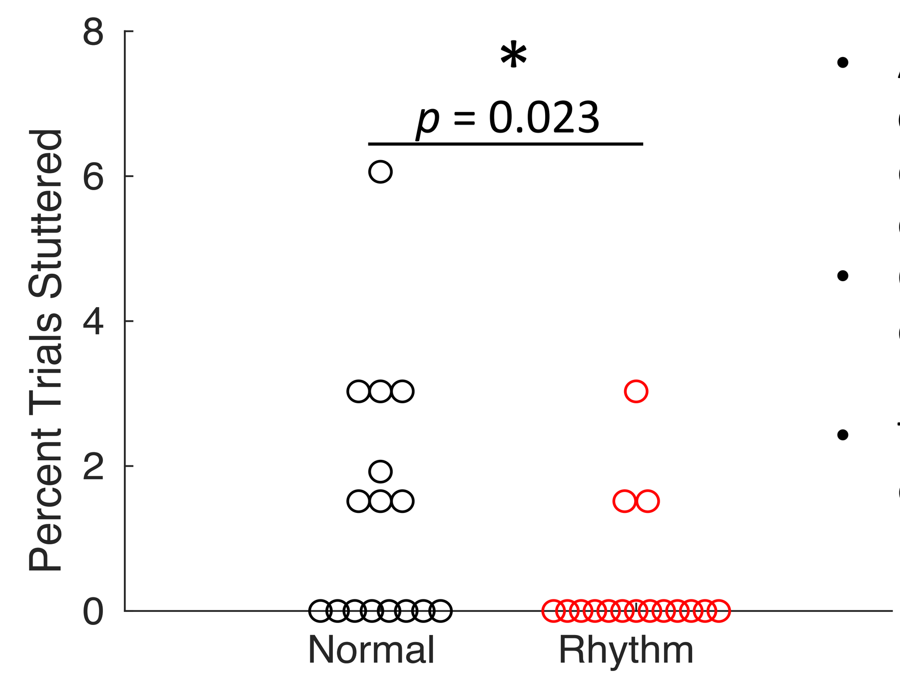
Table 1. Rate and Rhythmicity Stats

Measure	Main effect of Group:	Main effect of Condition:	Interaction:
Speaking rate (IVI/sec)	*F*(1,31) = 0.1, $p_{FWE} = 1$	*F*(1,31) = 54.7, $p_{FWE} < 0.001$	*F*(1,31) = 0.6 $p_{FWE} = 0.92$
CV-IVI	*F*(1,31) = 0.1, $p_{FWE} = 1$	*F*(1,31) = 492.0, $p_{FWE} < 0.001$	*F*(1,31) = 1.4 $p_{FWE} = 0.48$

References

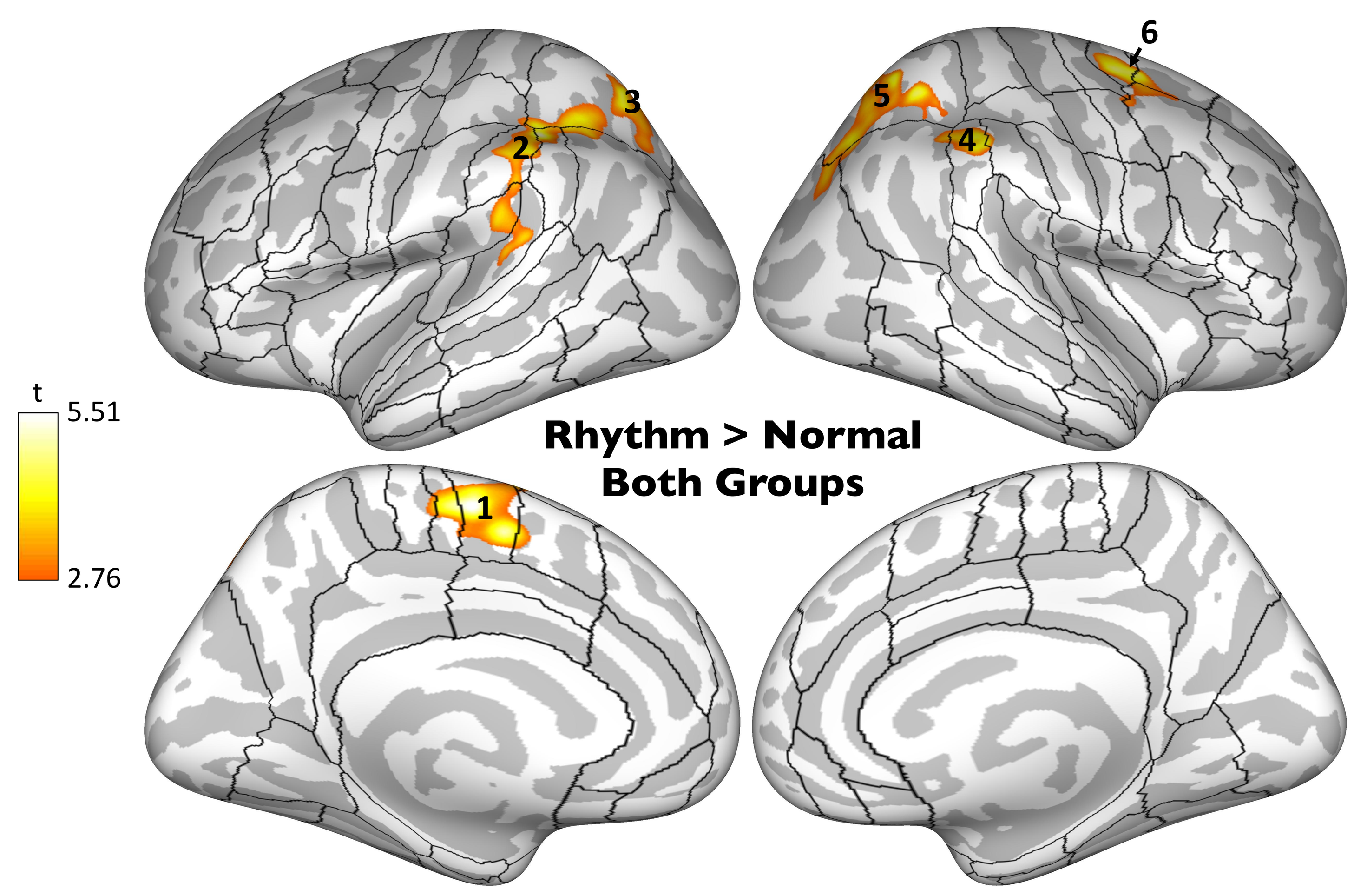
[1] Alm, P. A. (2004). *J. Commun. Disord.* 37, 325–369
[2] Andrews, G., Howie, P. M., Dozsa, M., & Guitar, B. E. (1982). *JSHLR*, *25*, 208-216.
[3] Toyomura, A., Fujii, T., Kuriki, S. (2011). *Neuroimage,* 57, 1507-1516.
[4] D. G. McLaren, M. L. Ries, G. Xu, and S. C. Johnson. (2012). *NeuroImage*, *61*, 1277–1286.

Figure 3. Disfluencies



- AWS produced **significantly fewer disfluencies** in the *rhythm* condition than in the *normal* condition
- Change in disfluencies was not correlated with change in speaking rate (*r* = -0.07, *p* = .80)
- The "rhythm effect" worked as expected

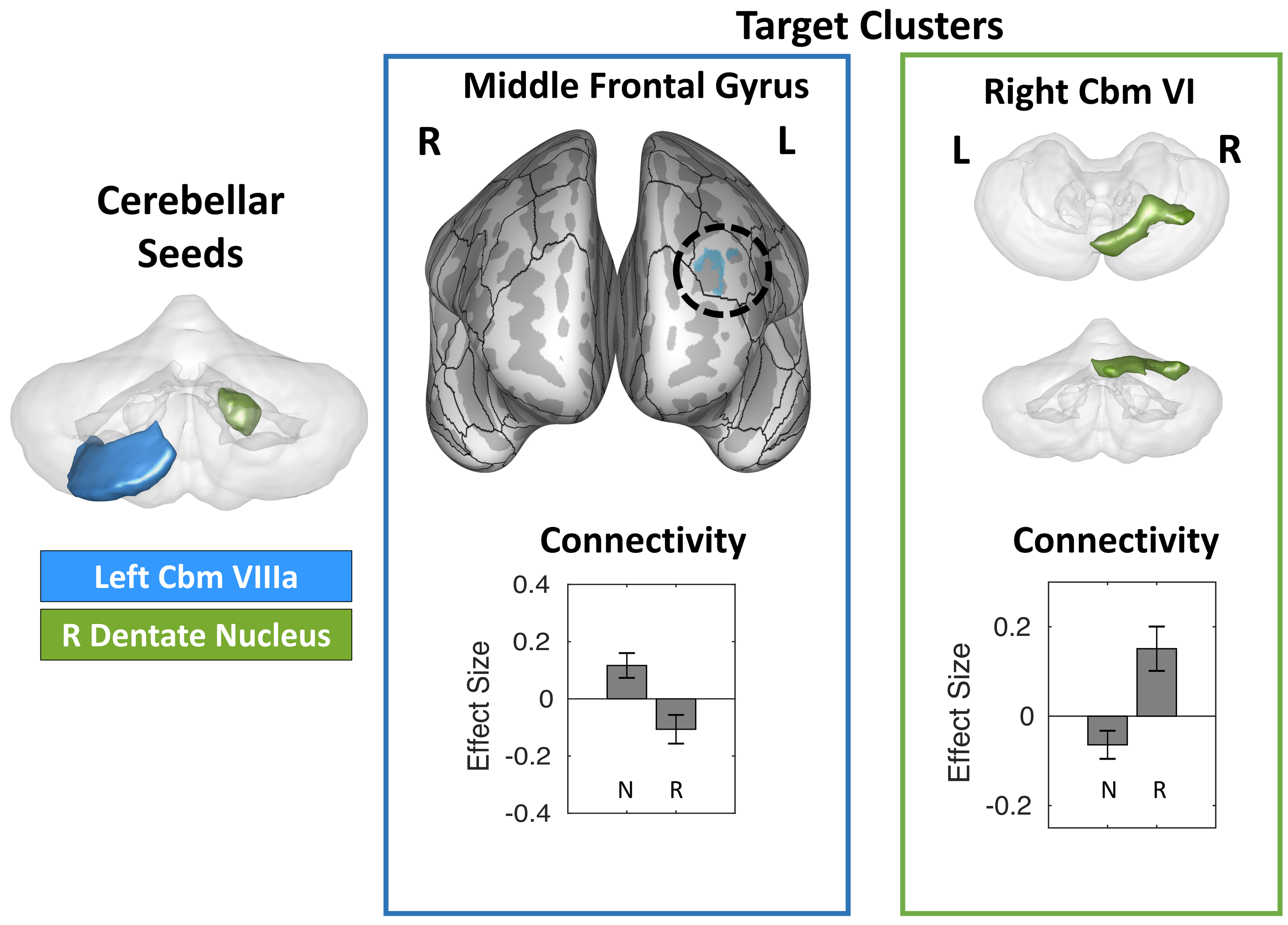
Figure 4. Task Activation



Controlling for speaking rate, the *rhythm* condition yields **greater activation** than the *normal* condition in left supplementary motor area (**1**), temporo-parietal junction and intraparietal sulcus (**2**), posterior superior parietal lobule (**3**), and right posterior supramarginal gyrus (**4**), superior parietal lobule (**5**), and dorsal premotor cortex (**6**)

Figure 5. Functional Connectivity

Rhythm vs. Normal, AWS



- AWS had ***decreased connectivity*** between left cerebellar lobule VIIIa and left anterior middle frontal gyrus VI during the *rhythm* condition compared to the *normal* condition
- AWS had ***increased connectivity*** between right dentate nucleus and right cerebellar lobule VI during the *rhythm* condition compared to the *normal* condition

Conclusions

- Isochronously-paced speaking yields greater recruitment of cortical regions that mediate motor initiation (L SMA), working memory (L IPS), attending to stimulus timing (L IPS), and sensory feedback control (L PT/ bilateral SMg/R dPMC)
- This type of speech also leads to increased cerebellar functional connectivity compared to non-paced speech in AWS
- The cerebellum may be recruited in AWS to compensate for an impaired internal timing mechanism involving the basal ganglia and supplementary motor area

Funding: This work was supported by the NIDCD of the National Institutes of Health, award numbers R01 DC007683 and T32 DC013017.

NIDCD
National Institute on Deafness and Other Communication Disorders