Behavioral and neuroanatomical characterization of stimulation-induced speech arrest

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Introduction

For decades, **cortical stimulation mapping (CSM)** has served as the "gold standard" for identification of eloquent cortex before resective neurosurgery[1]. **Speech arrest (SA)**, the cessation of speech output while the patient performs a stereotyped task such as counting, is often considered the functional mapping of Broca's area. However, definitions of SA vary considerably among historical accounts of SA[2,3].

This work aimed to establish a comprehensive and quantitative behavioral and neuroanatomical characterization of speech arrest and other speech disruptions that arise from intraoperative CSM.

Methods

- N = 34 epilepsy, glioma, and cavernous malformation patients
- Inclusion criteria:
  1. Awake left hemisphere craniotomy involving CSM.
  2. First resective brain surgery.
  3. Fluent speaker of English.
- Patients counted from one to thirty while surgeon administered direct electrical stimulation to cortex.
- Errors were classified as speech arrest (SA), a **motor error (ME)**, or a lexical error.
- Standard CSM tasks (sensorimotor mapping, picture naming, repetition) were also performed.
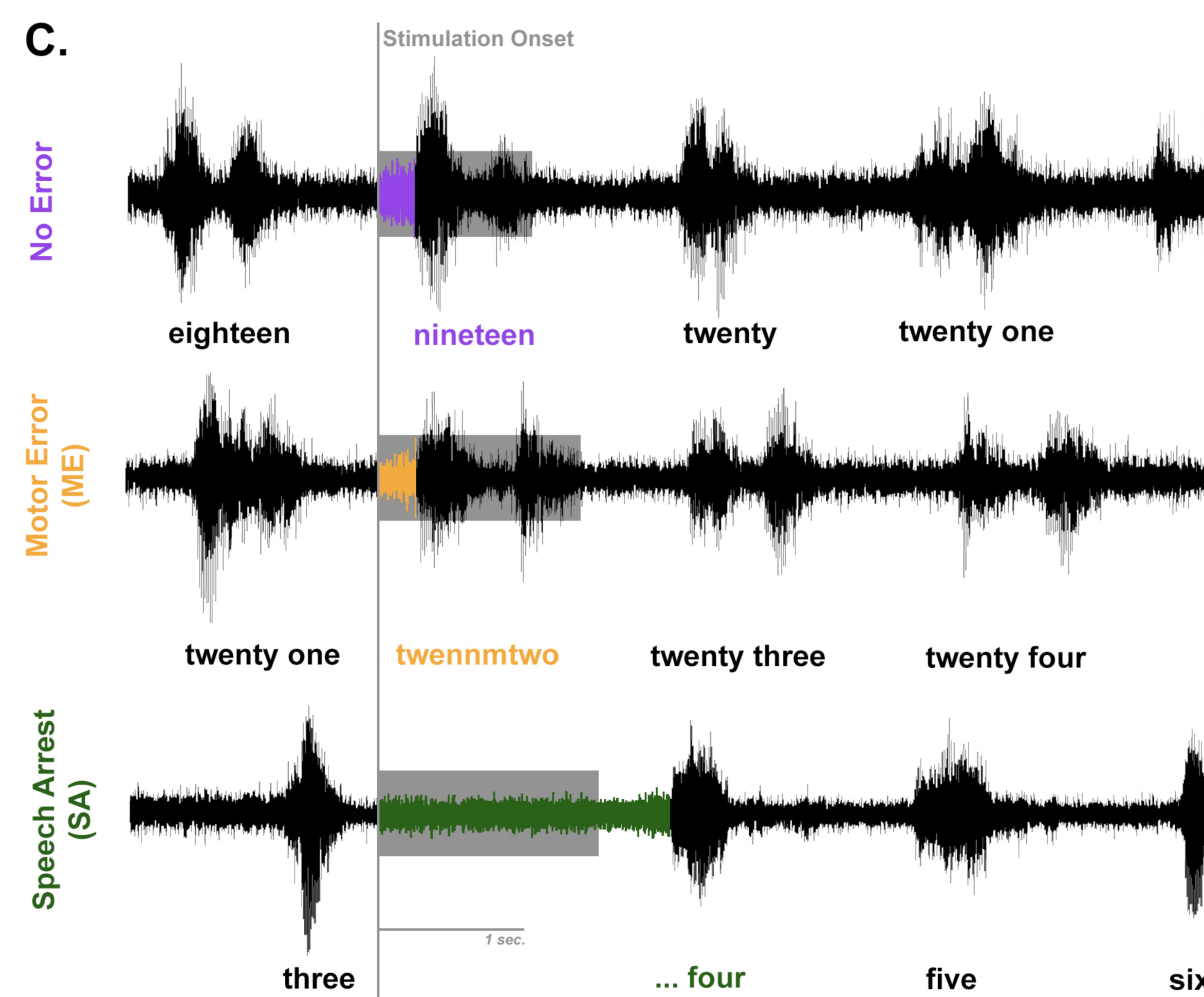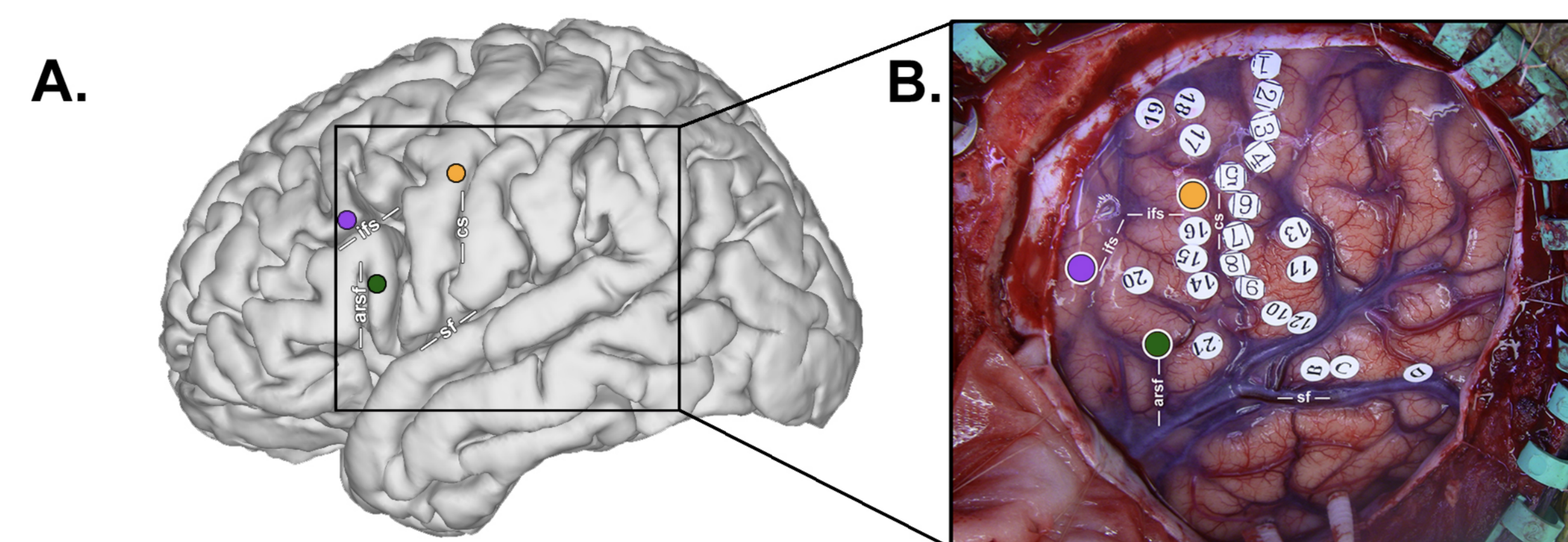
1, 2, … 29, 30

Monday … Friday

January … December
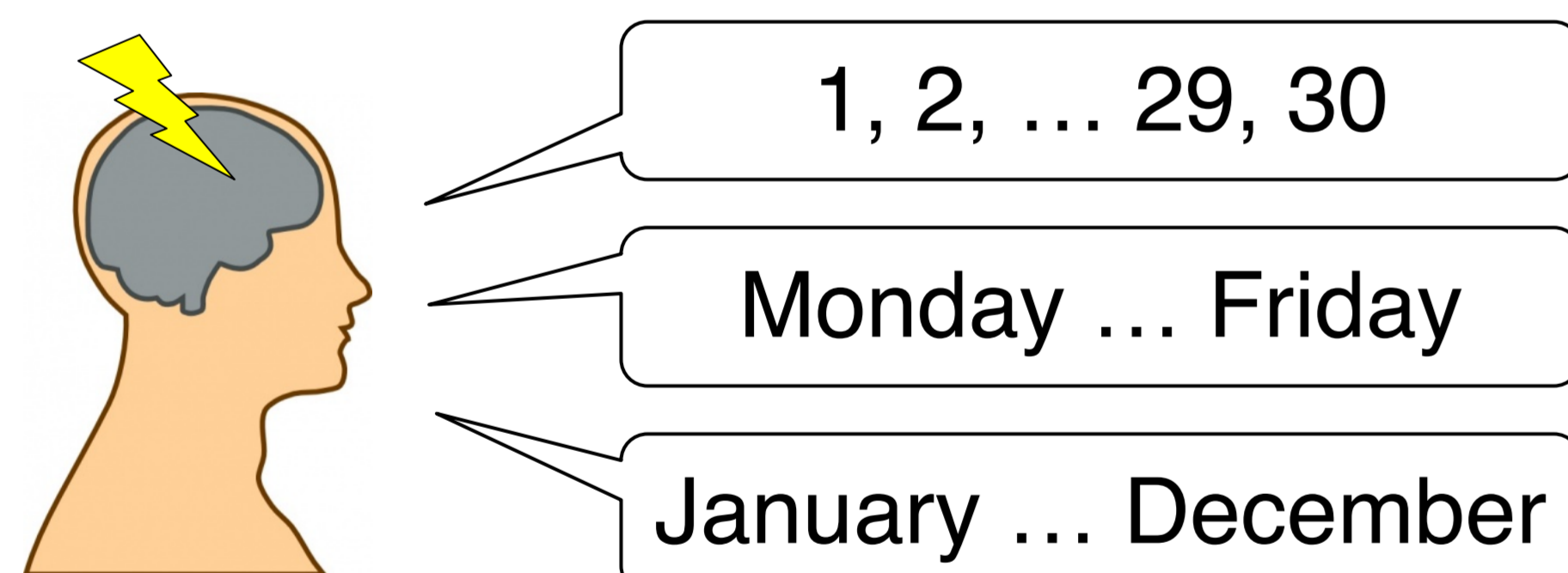
Results

Types and quantities of observed stimulation-evoked errors with corresponding examples of patients' self-reports:

| Error type	Example target	Example response	Example self-reports	#
Speech Arrest	four	…four	"I couldn't say thirty seven." "It was hard to keep going." "I can hear, but I can't get the words out." "You're slowing me down, man."	92
Motor Error	twenty-two	twennmtwo	"On the right side, it was my tongue." "I had a buzz or a feeling down my throat." "My jaw."	193
Lexical Error	twenty-nine	twenty-four	"Sorry, I got a little stuck."	6
Phonological paraphasia	thirteen	thirskrin	N/A	0

(A) shows 3 example stimulation sites on an MNI template brain.
(B) shows site locations on an intraoperative craniotomy.
(C) shows waveforms of the patient's speech before, during, and after stimulation, aligned to onset of stimulation. Grey bars indicate duration of stimulation. Colored portions of waveforms indicates response times (= speech onset - stimulation onset).

A. B.

C.

Stimulation Onset

No Error

eighteen   nineteen   twenty   twenty one

Motor Error (ME)

twenty one   twennmtwo   twenty three   twenty four

Speech Arrest (SA)

three   … four   five   six

1 sec.

Compared to **No Error** trials, speech onset was delayed longer for **Speech Arrest** trials than for **Motor Errors**. Scatterplots show speech onset relative to offset of electrocortical stimulation for all trials by error type. Only **Speech Arrest** trials were reliably delayed until stimulation offset.
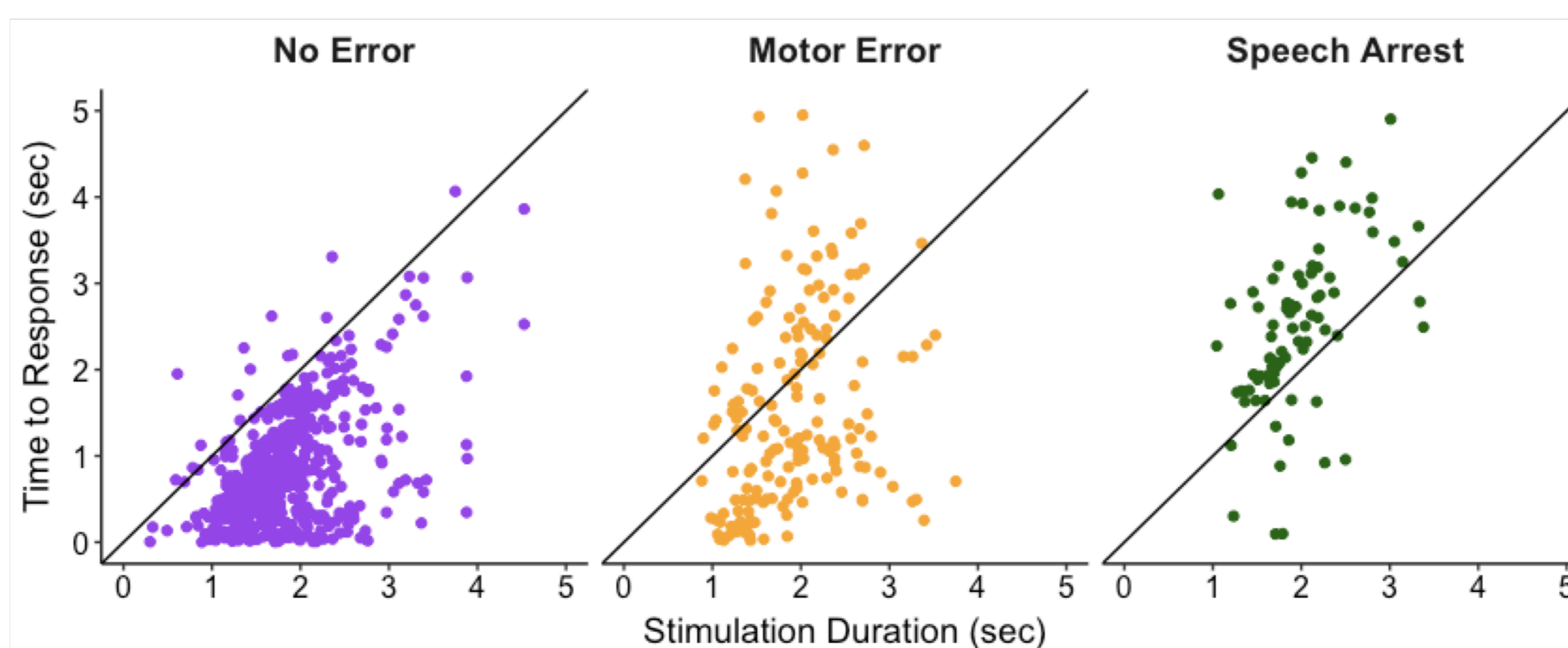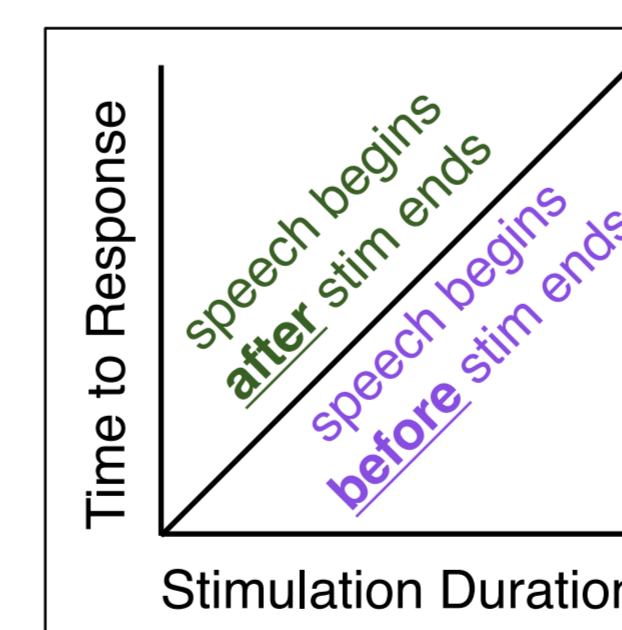
- 86% of sites where stimulation elicited **SA** or **ME** (black dots) were in precentral gyrus (**PCG**) or pars opercularis (**parsOp**).
- PCG was divided into 4 quadrants: dorsal/ventral & rostral/caudal.
- 71% of **SA** errors resulted from stimulation to **parsOp** & **vrPCG**.
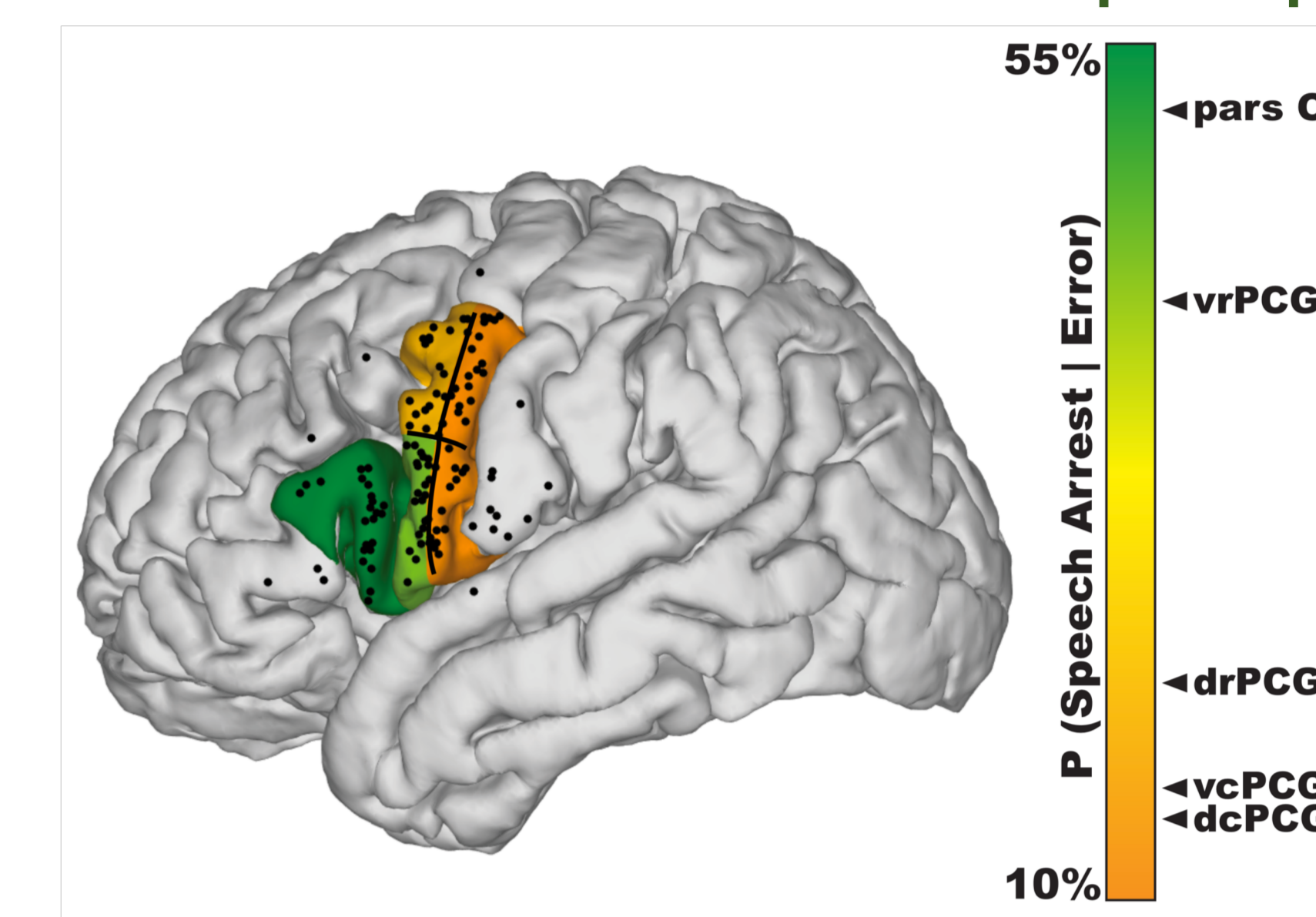
All stimulation trials, split by error type and anatomical region:

	Total stimulation trials	Stimulation Before Speech Onset				Stimulation After Speech Onset			
		No Error	Motor Error	Speech Arrest	Lexical	No Error	Motor Error	Speech Arrest	Lexical
dcPCG	89	30	34	6		19			
vcPCG	72	29	22	4		15	2		
drPCG	129	70	28	8	1	17	4	1	
vrPCG	227	113	43	31		38	2		
parsOp	291	159	30	33	3	62	3	1	
parsTri	94	63	5	6		20			
MFG	68	52	2		1	13			
PostCG	66	32	16	1	1	14	2		
IPL	2	2							
STG	6	5		1					
total:	1044	555	180	90	6	198	13	2	0

Discussion

- Better understanding/classification of SA informs clinical practice and theoretical models of speech production.
- SA temporarily halts speech output without concomitant motor disruption or general cognitive impairment.
- SA is an error in "speech packaging," an inability to properly package pre-articulatory speech into articulatory code[4].
- MEs elicited by disruption of articulatory/motor speech programming.
- Pars opercularis and precentral gyrus (BA44, vBA6, M1) are areas along a continuous dorsal speech production pathway[5].

Acknowledgements

References

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