A case of pure apraxia of speech after left hemisphere stroke: behavioral findings and neural correlates

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Pure Apraxia of Speech: Behavioral Measures

Apraxia of speech (AOS) is a **motor speech** disorder characterized by slow speech rate, segmentation of syllables, sound distortions, distorted substitutions, trial-and-error articulatory movements, and increased difficulty with increased length and complexity of utterances (Duffy, 2013). Pure AOS following stroke is rare, as it most often co-occurs with Broca's aphasia.

Different brain areas associated with AOS:

- The superior precentral gyrus of the insula (SPGI; Dronkers, 1996; Ogar et al., 2006; Baldo et al., 2011)
- Broca's area (Alexander et al., 1989, Hillis et al., 2004)
- The parietal lobe (Square, Roy, and Martin, 1997)
- Subcortical regions such as the basal ganglia (Peach & Tonkovich, 2003).
- The frontal aslant has been implicated in verbal fluency (Catani et al., 2013).

The goal of the current study was to explore patterns of apraxic speech errors and underlying neural correlates in a case of pure AOS.

- The participant was a 67-year-old right-handed man with initially severe AOS resulting from a large frontal lesion caused by an ischemic stroke The participant's speech and language were evaluated at 1.5 months, 3 months, and 10 months post-onset.

Performance on language measures was within normal limits

Comprehensive Aphasia Test	1-month post-onset	3-months post-onset
Cognitive Screen (_/38)	35	37
Memory (_/20)	19	20
Auditory Comprehension (_/66)	61	66
Written Comprehension (_/62)	59	62
Repetition (_/74)	48	60
Naming Objects (_/48)	48	48
Naming Actions (_/10)	10	10
Spoken Picture Description	32.5	45
Reading (_/70)	70	70
Writing (_/76)	76	76
Written Picture Description	17	29
Western Aphasia Battery- Revised		
Aphasia Quotient	94.5	98.2
Curtiss–Yamada Comprehensive Language Evaluation-Receptive (CYCLE-R)		
(CYCLE-R) raw score	54 (90.0%)	56 (93.3%)
Northwestern Naming Battery /Northwestern Assessment of Verbs & Sentences		
Naming nouns	100%	100%
Naming verbs	100%	100%
Sentence production priming	83%	100%

Motor Speech Evaluation

- At 1-month post onset, the participant's AOS severity was **rated as 5** (out of 7) **and improved to 4** by his 3-month visit due to careful slowing of speech.

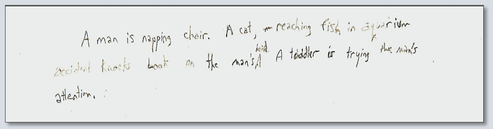
Assessment at 8 months post-onset

- AOS score was still considered **moderate** (4 out of 7)**.**
- **Maximum phonation time** (MPT) of 16 seconds on sustained "ah"
- Relatively intact sequential motion rates (SMR, (p^p^p^) with **breakdowns in sequencing on alternating motion rates** (AMRs p^t^k^) resulting in voicing errors (t→d, k→g), transposition errors (t^p^k^).
- **Vowel changes** observed on both SMRs and AMRs, but with increased frequency on SMR /k^/ (^→ae), which may reflect demand for placement of articulator (e.g., glottal K influencing shift from /^/ to /æ/) .
- On multisyllabic word repetitions, the participant demonstrated a similar pattern of **voicing, assimilation, and substitution errors** as well as syllable deletions on targets "artillery" and "catastrophe" (/ætr^li/, / æktɪlɜi/, /k^tæsr^si/).

Summary of behaviors observed:

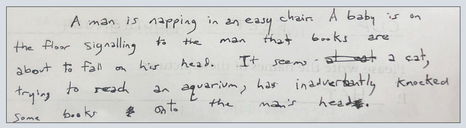
- Phonemic anticipatory errors
- Phonemic perseverative errors
- Phonemic transposition errors
- Phonemic voicing errors
- Phonemic vowel errors
- Visible/audible searching
- Inconsistent errors
- Increased errors with increase in phonemic sequence
- Few errors in automatic speech
- Abnormal prosodic features

1-month post-onset CAT writing subtest:
participant shows mild agrammatism



"A man is napping chair. A cat, reaching fish in aquarium accident knocks books on the man's head. A toddler is trying the man's attention."

3-months post-onset CAT writing subtest:
participant shows no agrammatism



"A man is napping in an easy chair. A baby is on the floor signalling to the man that books are about to fall on his head. It seems a cat, trying to reach an aquarium, has inadvertantly knocked some books onto the man's head."

Neuroimaging

Diffusion-weighted MRIs (50 directions at b=1000s/mm2 and b=2000s/mm2, 2mm isovoxel, b=2000s/mm2, 10 b0 volumes) were acquired on a Siemens Verio 3T scanner. Whole brain probabilistic tractography based on the fODF (15º angular threshold) was obtained and tracts of interest were manually segmented in Mi-Brain using a ROI-based approach.

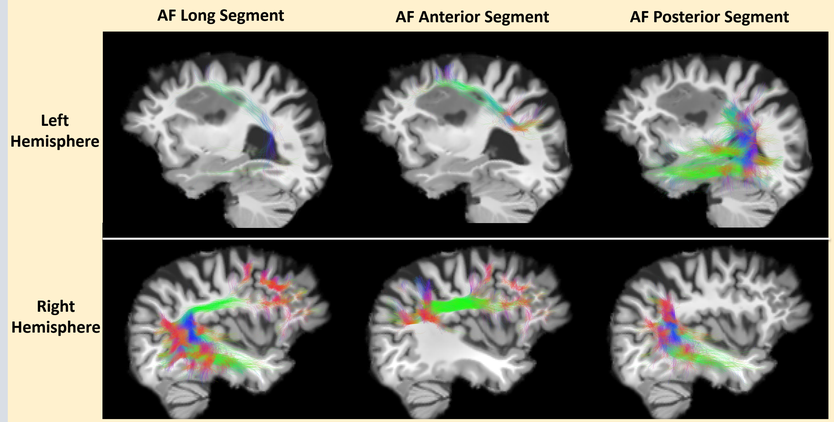
Arcuate fasciculus (AF) (according to Catani 3-segment model)

- **Long segment AF**: fiber pathway connecting frontal and temporal lobes.
- **Posterior AF**: fiber pathway connecting temporal and parietal lobes.
- **Anterior AF**: fiber pathway connecting frontal and parietal lobes.

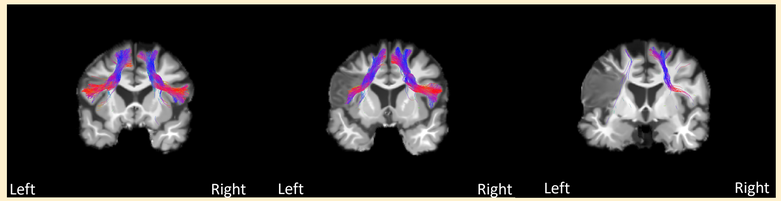
Frontal Aslant Tract (FAT) (Defined by 2 ROIs) –

- fiber pathway connecting **inferior frontal gyrus** (IFG) and the **supplementary motor area** (including pre-supplementary motor area).

Tract Reconstruction: Arcuate Fasciculus



Tract Reconstruction: Frontal Aslant Tract



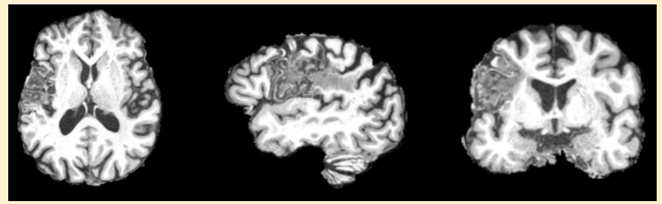
Fiber Tract Volumes

VOLUME (in 1mm voxels)	AF long segment	AF anterior segment	AF posterior segment	FAT
Left Hemisphere	7360	14282	38640	13919
Right Hemisphere	68029	57418	29917	18857

Mean Fractional Anisotropies

Mean FA	AF long segment	AF anterior segment	AF posterior segment	FAT
Left Hemisphere	0.31	0.3	0.32	0.3
Right Hemisphere	0.43	0.42	0.38	0.36

- **Left AF < Right AF** volume in all tracts **except for posterior AF**, which reflects the natural asymmetry of AF. Left anterior AF is impacted by lesion. Mean FA of left AF is slightly less than right AF.
- **Left FAT** has reduced volume and mean FA when compared to right FAT. Only the **cortex-reaching fibers** appear to be affected in left FAT.



T1 MRI obtained scans at 1.5 months post-onset showing left hemisphere infarct, encompassing the **precentral gyrus, the superior precentral gyrus of the insula, and surrounding white matter. Broca's area was spared, except for the most posterior part of BA 44.**

Conclusions

A **pure case of AOS** was confirmed from the behavioral data showing **non-aphasic performance on language tests** and a rating of moderate AOS on motor speech tests.

Speech errors persist while language is normal

- The participant initially exhibited mild agrammatism, which resolved within the first 3 months post-onset.
- The participant continued to make speech errors typical of AOS.
- He scored perfectly, or within normal limits, on all CAT subtests except **repetition,** struggling with **longer words and consonant clusters**, typical of AOS.
- He also struggled with the CAT spoken picture description, which is scored in large part on the raw number of information carrying words produced. Due to **difficulty producing speech at a normal rate**, his 3-minute description was short but non-aphasic after 3 months post-onset.
- Interestingly, the participant produces fluent speech in song.
- The participant struggled with consonant clusters, typical of AOS, also producing distorted vowel sounds.
- The **vowel distortion may be an assimilation error.** When moving from one phoneme to the next, the consonant tongue placement could influence the vowels sounds around them.

Brain regions & white matter pathways

- This pure case of AOS points to the crucial role of the **SPGI** in AOS deficits, along with possible contributions of surrounding cortical areas and fiber pathways such as the **frontal aslant tract** and the **anterior arcuate fasciculus.** Notably, the rest of the anterior insula is preserved in the participant, supporting the specific contribution of the SPGI to motor aspects of speech.
- The **left hemisphere FAT** was only damaged in extensions to the cortex, raising questions about these cortex-reaching projections and their role in motor-speech coordination and fluency.

Future directions

- At 1-year post-onset, an in-person language evaluation and updated neuroimaging data are needed to determine the chronic status of the lesion and its behavioral effects.
- Due to the pandemic, the participant could only be scanned at 1-month post-onset. The behavioral data after 1-month post-onset were gathered online via video calls.
- A longitudinal study of the participant will allow observation of the unique neural reorganization that occurs after stroke-induced pure apraxia of speech.

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