Differences in Word Usage Patterns between "Well-Recovered" Aphasic Patients and Control Subjects on a Picture Description Task

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PERSONAL SECTION

When I was in middle school, my mom gave me a book of computational linguistics problems from the Soviet Olympiads. The puzzles required no knowledge of linguistics as such – they tested logic as applied to language. I've always loved both logic and language, so I had a blast. I started taking the North American Computational Linguistics Olympiad (NACLO) each year.

In tenth grade, I discovered that a friend, Alan Du, had also taken NACLO for years. Together, we decided to start a Linguistics Club at our school. At first, we focused solely on NACLO practice. I worked on setting up our school's test site, which soon became one of the most successful in the nation. Gradually, we also introduced student lectures about the science of language. We started learning haphazard bits of syntax and phonology and pragmatics, but we got stuck pretty soon. There's no textbook for teenagers curious about the Chomsky–Schützenberger Hierarchy, and we had trouble putting together any sort of coherent curriculum.

I wrote to a few linguists at the nearby University of Maryland (UMD), asking them to give us guest talks. I wasn't particularly expecting replies – surely, professors were too busy to come teach high-schoolers. To my surprise, the whole department responded enthusiastically. Over the next three years, we had dozens of guest speakers from UMD and other eminent institutions, with annual field trips to UMD's Linguistics Department. I got to know linguists from around the country, and discovered that they're consistently passionate, wonderful people – people who do their research because they love it, and are always eager to share with curious students. I learned about babies and brains and computer algorithms, and started to see how much math and science matter in the study of language.

One topic that I found particularly striking was aphasia, a quite common condition in which patients lose linguistic abilities. Aphasia is usually caused by stroke, head trauma, or progressive illness, and can vary hugely in its symptoms – some patients lose any ability to use or understand language; some have unimpaired vocabularies, but become unable to construct basic sentences; some have few grammatical issues, but can't call to mind the simplest words.

I couldn't imagine how terrifying it must be to lose the ability to express thoughts in words, or to understand words written and spoken around me. I wanted to learn more about the subject.

In eleventh grade, I started looking for a summer internship in neurolinguistics. I found Dr. Allen Braun's lab at the National Institutes of Health, which uses neuroimaging techniques to study language production in the brain. Dr. Braun took me on as a volunteer on a study of a particular population of aphasic patients – people who had recovered so well that they scored at near-normal levels on the standard assessments, but yet experienced lingering difficulties. Often, these patients had normal vocabularies and could put together sentences, but they couldn't carry on coherent conversations or process whole documents. This made it very challenging for them to carry on their personal and professional lives – but because they were considered recovered, they had trouble securing further treatment.

Initially, I was asked to score these patients' speech transcripts for the amount of non-repetitive information, and for adherence to story structures. While I was scoring the transcripts, it bothered me that the work was inherently subjective – I couldn't be sure that I'd give the same piece the same score on two different days. I started looking for a more quantitative way to analyze the data, and showed my initial results to my mentor, Dr. Siyuan Liu. Together, we came up with the idea of comparing aphasics' and controls' speech on a word-by-word level. I spent several weeks after that working out the details, learning about statistical techniques that might be useful, and implementing the analysis. The technique I came up with could someday be applied to create a diagnostic tool.

In this project, I was able to combine my interests in math and language to do work that someday could help people. I'd like to continue to do similar research – interdisciplinary and useful. My project gave me the chance to learn more about statistics and neuroscience, and also to meet a lot of wonderful people through my internship and science fairs. I hope to have the same sort of experience in the future.

RESEARCH SECTION

INTRODUCTION

Aphasia

Each year, nearly 800,000 people in the US suffer strokes [1]. Of these, about 38%, or 300,000, experience some degree of aphasia, or loss of linguistic abilities [2]. The severity and symptoms of aphasia vary widely, from “severe impairment across all language modalities” [3] to specific, limited problems such as reading difficulties [4]. Aphasia is typically associated with lesions (damaged tissues) in the left hemisphere of the brain [5]. The specific impairments involved depend in large part on the brain areas affected by the stroke [6]. Regardless of symptoms, many aphasic patients show marked improvement over time, with some studies reporting up to 40% of patients recovering completely within a year of the stroke [7].

The Western Aphasia Battery (WAB) [8] is one of several standard tests for evaluating the degree of linguistic impairment. Such tests measure impairments at the phonological, lexical, and syntactic levels [9]. They do not, however, measure impairments at the level of discourse. Many patients who score very well on the WAB, and so are considered to be recovered, still complain about lingering deficits on the discourse level. Such patients may experience serious difficulties with communication in their personal and professional lives [10]. Since little research has been done to systematically study this issue, there is a pressing need for new diagnostic tools to quantify such deficits and for a better understanding of the underlying neural mechanisms.

MRI and Voxel-Based Lesion-Symptom Mapping

Magnetic resonance imaging (MRI) is a medical imaging technique that uses a magnetic field and radio pulses to detect water molecules in the body, and specifically can be used *in vivo* to produce high-definition brain images [11]. As different brain tissues have different nuclear magnetic resonance properties, MRI is able to discern various tissue types and produce detailed maps of the brain. MRI images are recorded in the unit of the voxel, which contains a numerical value reflecting the image intensity of the tissue located at the voxel's corresponding geometric coordinates (typically, a rectangular prism several millimeters long).

Voxel-based lesion-symptom mapping (VLSM) [12] is a method used to associate lesion locations with particular behavioral deficits on a voxel-by-voxel basis. For each voxel, patients are divided into two groups: those with a lesion overlapping that voxel, and those without. The two groups are compared with regard to some data set, such as scores on a particular behavioral task, using a non-parametric statistical test such as a Mann-Whitney-Wilcoxon test or Wilcoxon signed-rank test. A significant difference in behavioral scores between the two groups indicates that damage to this voxel is correlated with deficits in the cognitive brain functions necessary for the task.

Purpose of Project

In this project, I analyzed the differences in word use between "well-recovered" aphasic patients (those that perform well on the Western Aphasia Battery) and normal control subjects on a discourse task. Although the aphasic patients exhibited near-normal performance on the word and sentence levels, they produced different patterns of text structure and word use than normal subjects. This project introduced a methodology for statistically analyzing these differences in word use. In the future, a similar approach could be used to develop a diagnostic tool to identify patients with discourse impairments, based on analysis of the words used in a short transcript of speech. Such a tool would be a quick and easily administered addition to a standard aphasia testing battery, and allow for diagnosis and treatment of this severely understudied and underserved population.

In addition, the VLSM analysis of the measures of word use revealed areas of the brain associated with deficits, which indicated possible causes of these behaviors. Such knowledge of the underlying causes would allow discourse problems to be addressed more easily in a clinical setting.

METHODS

Data Collection

The data used in this project had been previously collected in the laboratory by other researchers. The participants were 18 post-stroke aphasic patients, considered "recovered" because they had received scores of at least 85 out of 100 on the Western Aphasic Battery (WAB) Aphasia Quotient, as well as 16 control subjects. The two groups did not differ significantly by age or years of education by a Student's t-test with $p = .10$. The project was approved by an Institutional Review Board, and each subject gave informed written consent to undergo behavioral testing and Magnetic Resonance Imaging brain scans. The tests included the WAB, which was used as a selection criterion, and a picture description task. In the picture description task, each subject was shown three Norman Rockwell paintings in turn, and given two minutes to describe each painting. The audio of each picture description was recorded and later transcribed.

For each subject, a specific type of MRI image, T2 Fluid Attenuated Inversion Recovery, of the whole brain was acquired in order to provide clear contrast between damaged and normal tissue. A neuroimaging expert manually delineated lesions. For analysis across subjects, individual brain images were standardized by warping them onto the standard Montreal Neurological Institute template.

Description Editing

I edited description transcripts to account for inconsistent transcription techniques. Each subject's three painting descriptions were combined into a single passage. Contractions were considered as single words. Unorthodox spellings used to account for unusual pronunciations (e.g. "sssit") were corrected to the normal form. Words with different spellings (e.g. "grey" and "gray") were put into a consistent form. Compound words were put into consistent forms, either as two words (e.g. "baseball-field") or one word (e.g. "t-shirt").

Content Unit Scoring

I scored each discourse sample for the number of content units, a measure of non-repetitive information communicated, using an approach based on Yorksteon and Beukelman [13]. By this system, multiple references to the same object (e.g. "the man", "the doctor", "the physician") were considered as a single content unit, while additions of new information (e.g. "the coat", "the white coat") were considered separate content units.

Numerical Analysis

I used Java, Excel, and R to quantitatively analyze data. The number of times each subject used each word was counted and recorded. For subsequent analyses, data were standardized by replacing each word's absolute count per subject by the ratio of that word's uses to that subject's total words. This accounted for controls' larger average text samples. For each word, a Mann-Whitney-Wilcoxon test was used to compare the total-use portions between patients and controls. Words that were used fewer than 10 times total by all controls were excluded from further analyses. False discovery rate control was used to adjust for multiple comparisons; q-values below 5% were considered significant.

Words with significant differences in usage percent between patients and controls were sorted into categories according to their function in sentences. The categories used were nouns, syntax modifiers, location descriptors, adjectives, gerunds/participles ending in "ing", appearance indicators, and words of mixed or indeterminate use. A full list of significant words and categorizations is available in Table 2 of the Results section. Categories were verified by manually checking each word's uses to make sure that the vast majority of uses corresponded to the category function.

Lesion Mapping

I modified the categories for use in voxel-based lesion-symptom mapping (VLSM) on aphasic patients' scans. Words that were used more frequently by patients than by controls were excluded from categories and considered separately. Words of mixed or indeterminate use were excluded. Three values in addition to word use portions were considered for each subject: total number of content units, total number of words, and content ratio (the ratio of content units to total words).

VLSM was performed with a program that had previously been written in our laboratory. A Mann-Whitney-Wilcoxon test was used to identify the brain areas in which lesions were associated with unusual use (defined as increased use for those words used more by patients, and decreased use for those words used more by controls). Due to the limited number of subjects, a correction for multiple comparisons across voxels was not applied. A neuroimaging expert identified the brain areas surrounding each voxel group by visual inspection.

RESULTS

In total, the 18 aphasic subjects produced 7753 words (average 440 per subject) and the 16 control subjects produced 11188 (average 699 per subject). The two groups together used 1485 distinct words. The ten most commonly used words for aphasic and normal subjects, respectively, are displayed in Table 1.

Table 1: Most commonly used words for aphasic patients and for control subjects

Most commonly used words for aphasic patients				Most commonly used words for control subjects			
Rank	*Word*	*Uses*	*Percent*	*Rank*	*Word*	*Uses*	*Percent*
1	the	558	7.20%	1	the	970	8.67%
2	and	426	5.49%	2	a	486	4.34%
3	uh	336	4.33%	3	and	403	3.60%
4	um	331	4.27%	4	uh	339	3.03%
5	is	231	2.98%	5	is	296	2.65%
6	a	214	2.76%	6	on	251	2.24%
7	to	147	1.90%	7	in	226	2.02%
8	i	110	1.42%	8	to	204	1.82%
9	on	104	1.34%	9	of	195	1.74%
10	of	96	1.24%	10	um	184	1.64%

"Percent" refers to the percentage of all words that each word constituted for that group.

Aphasic subjects produced a total of 1759 content units (average 98 per subject), and normal subjects produced a total of 4044 (average 253 per subject).

Of the 1485 unique words, 181 were used at least 10 times each by control subjects. Among these words, 34 had Mann-Whitney-Wilcoxon q-values below 5% false discovery rate. These words, sorted into categories according to function, are displayed in Table 2.

VLSM was conducted using these categories in slightly modified form: the three words of mixed or indeterminate use ("know", "in", and "on"), as well as the word "rain", were excluded. Representative VLSM images for each category are displayed in Figure 1, with significant voxels identified by VLSM superimposed in red. VLSM was also used to identify voxels associated with a low total number of words or content units (Figure 2).

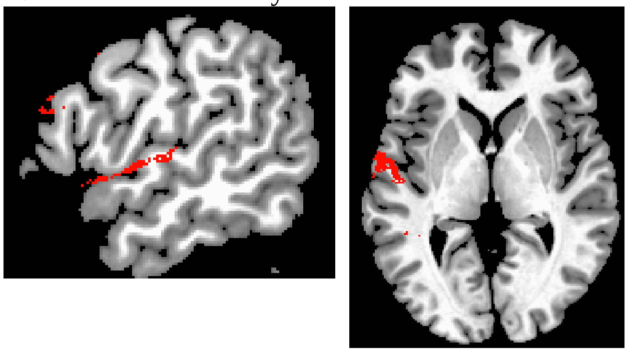
Table 2: Words used significantly more often by patients or by control subjects

Word	*Used more by*	*Q-value*	*Uses (patients)*	*Percent (patients)*	*Uses (controls)*	*Percent (controls)*
rain	Patients	3.52%	32	0.41%	22	0.20%
hand	Controls	0.61%	4	0.05%	53	0.47%
wall	Controls	0.67%	7	0.09%	51	0.46%
face	Controls	1.15%	0	0.00%	16	0.14%
office	Controls	1.40%	5	0.06%	27	0.24%
dress	Controls	1.60%	0	0.00%	10	0.09%
children	Controls	2.55%	12	0.15%	48	0.43%
hair	Controls	3.15%	1	0.01%	13	0.12%
bedroom	Controls	4.31%	5	0.06%	15	0.13%
and	Patients	2.16%	426	5.49%	403	3.60%
also	Controls	0.47%	5	0.06%	34	0.30%
with	Controls	1.03%	21	0.27%	106	0.95%
a	Controls	1.47%	214	2.76%	486	4.34%
which	Controls	1.49%	2	0.03%	17	0.15%
of	Controls	2.65%	96	1.24%	195	1.74%
corner	Controls	0.74%	0	0.00%	15	0.13%
background	Controls	2.40%	3	0.04%	28	0.25%
front	Controls	2.43%	0	0.00%	12	0.11%
bottom	Controls	2.66%	1	0.01%	11	0.10%
left	Controls	3.83%	4	0.05%	20	0.18%
down	Controls	3.88%	13	0.17%	38	0.34%
gray	Controls	0.52%	0	0.00%	19	0.17%
dark	Controls	0.64%	2	0.03%	21	0.19%
black	Controls	1.23%	1	0.01%	38	0.34%
white	Controls	3.42%	11	0.14%	62	0.55%
holding	Controls	1.64%	6	0.08%	39	0.35%
standing	Controls	1.88%	14	0.18%	59	0.53%
hanging	Controls	2.88%	2	0.03%	17	0.15%
wearing	Controls	4.98%	4	0.05%	30	0.27%
looks	Controls	1.28%	32	0.41%	136	1.22%
appears	Controls	2.49%	2	0.03%	29	0.26%
know	Patients	1.22%	44	0.57%	12	0.11%
in	Controls	1.11%	92	1.19%	226	2.02%
on	Controls	3.44%	104	1.34%	251	2.24%

The categories displayed are, in order, nouns, syntax modifiers, location descriptors, adjectives, gerunds/participles ending in "ing", appearance indicators, and words of mixed or indeterminate use. "Used more by" refers to the group which uses each word significantly more than the other. "Percent" refers to the percent of all words that each word constitutes for each group.

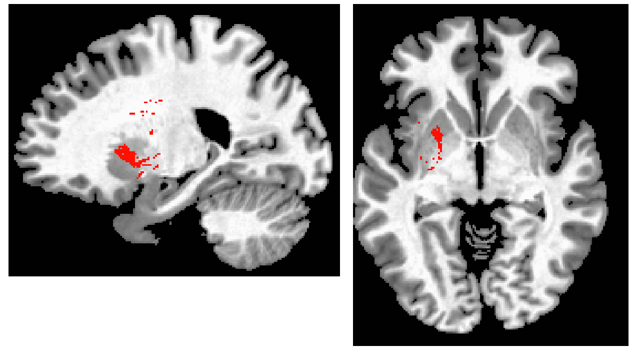
Figure 1. Representative images of voxel-based lesion-symptom mapping according to word categories

A. Nouns used more by controls



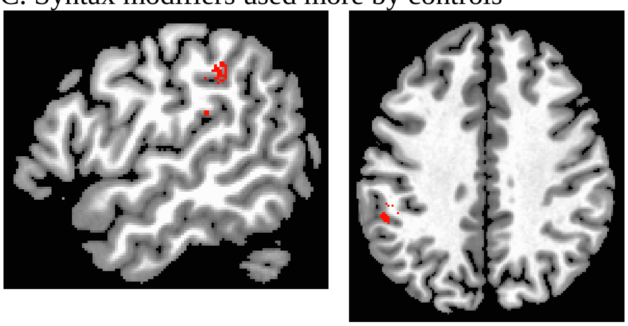
x = -55 *z = 1*

B. "And"



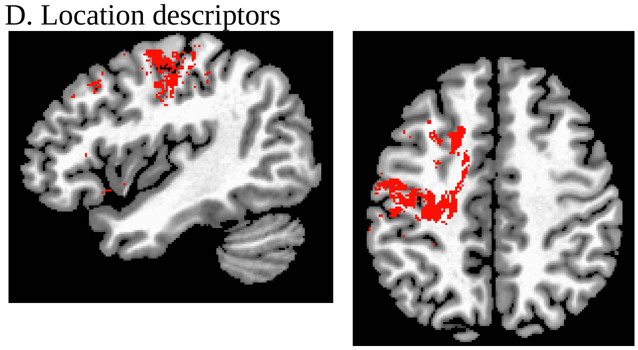
x = -21 *z = -5*

C. Syntax modifiers used more by controls



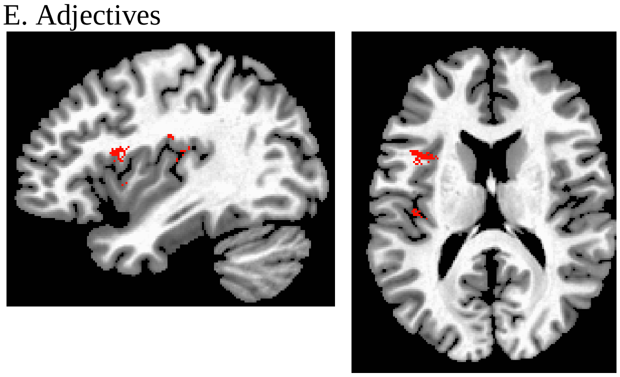
x = -53 *z = 37*

D. Location descriptors



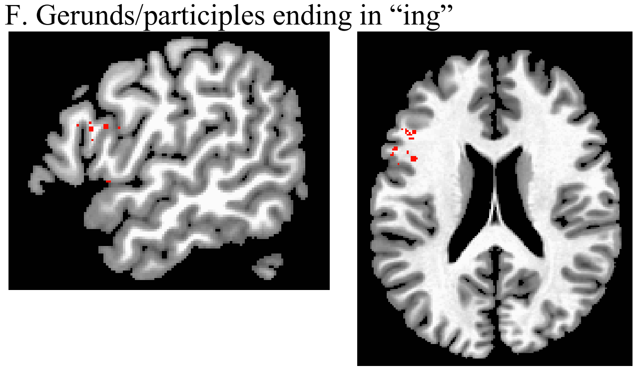
x = -42 *z = 44*

E. Adjectives



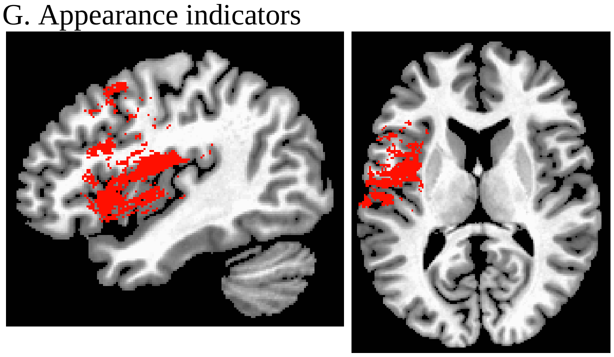
x = -38 *z = 13*

F. Gerunds/participles ending in "ing"



x = -54 *z = 19*

G. Appearance indicators

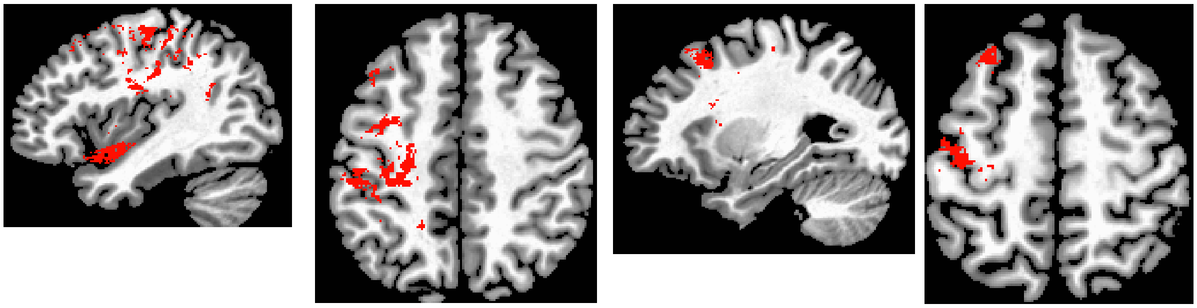


x = -41 *z = 9*

For each image, the black-and-white underlay image shows the brain's structural details. The superimposed red coloring depicts voxels that are associated with unusual use of words in the given category ($p < .05$, except for syntax modifiers for which $p < .08$). Patients that have lesions including these voxels are more likely to exhibit unusual behaviors. The given values for *x* and *z* refer to the distance (in millimeters) from the center of the brain to the pictured planes along the lateral-medial and anterior-posterior axes, respectively. Negative *x* values refer to slices in the left hemisphere.

Figure 2. Representative images of voxel-based lesion-symptom mapping according to total number of words and content units

A. Total number of words　　B. Total number of content units



x = -39　z = 44　x = -27　z = 54

For each image, red coloring depicts voxels that are associated with low total number of words or low total number of content units, respectively (p<..05). The given values for *x* and *z* refer to the distance (in millimeters) from the center of the brain to the pictured planes along the lateral-medial and anterior-posterior axes, respectively. Negative *x* values refer to slices in the left hemisphere.

Each of the brain area surrounding large voxel groups has been studied in previous literature. Table 3 displays selected known or proposed functions of each area.

Table 3: Identified brain areas and functions

Word category/usage measure	*Brain areas (in left hemisphere)*	*Selected known or proposed functions*
Nouns used more by controls	Anterior temporal lobe, inferior frontal gyrus	Semantic memory [14], lexical selection [15]
"And"	Putamen (basal ganglia)	Reinforcement learning, motor planning, movement sequencing [16][17]
Syntax modifiers used more by controls	Angular gyrus	Working memory, sentence comprehension [18]
Location descriptors	Superior frontal sulcus, superior frontal gyrus, motor cortex	Working memory [19], spatial orientation [20]
Adjectives	Insula	Speech motor planning [21]
Gerunds/participles ending in "ing"	Middle frontal gyrus	Attention, working memory [22-24]
Appearance indicators	Insula, middle and superior frontal gyrus	Speech motor planning, attention, working memory [21-24]
Total number of words	Superior frontal sulcus, insula	Working memory [19], speech motor planning, attention [21-24]
Total number of content units	Superior frontal sulcus, motor cortex	Working memory [19], speech motor control [25]

Brain areas that VLSM indicated may be associated with each usage measure, as well as functions that have been linked to each in previous research.

DISCUSSION

This investigation identified differences in word usage between normal subjects and "well-recovered" aphasic patients, indicating that even these "well-recovered" patients have persistent speech deficits at the discourse level. It also located brain areas in which lesions may be responsible for these deficits. It is important to note that, because no correction was applied for multiple comparison and because thresholds were not selected consistently, the VLSM results do not imply that these brain areas are certainly related to these behavioral deficits. Rather, they are used to show the trends of voxels that are more likely to be associated with these deficits.

With the exception of "rain", "and", and two words of indeterminate use, all of the words with significant differences between the two groups were used more by control subjects than by patients. Most of these words are used either to establish syntactic structures or to offer details.

The aphasic subjects' trend toward using fewer descriptive terms may indicate that they have trouble recalling specific detailed terms, or that they economize words that are not strictly necessary because they find talking a greater cognitive burden than do control subjects. The fact that aphasic subjects produced significantly fewer words and fewer content units on average lends credence to the second explanation. Difficulty planning and controlling the actions of speech could easily lead to a stress on economizing words; similarly, difficulty holding in memory a large amount of information could make it more difficult to produce large amounts of speech. Further supporting this interpretation, many discourse deficits were linked with lesions in frontal and subcortical areas. These areas are known to be related to motor planning and to complex cognitive functions such as working memory and attention, which are not traditionally associated with language production. This suggests that such non-linguistic tasks and brain areas should be considered when evaluating and treating discourse-level linguistic impairments; patients with impaired working memory, attention, or motor skills are likely to have impaired discourse.

The fact that control subjects used more words with syntactical functions indicates that controls were more likely to use complex sentence structures. This suggests that for aphasic subjects, storing information about a long and complex sentence presented a large cognitive burden; this theory is consistent with the fact that several of the implicated brain areas are linked to working memory processes.

The word "and" was used more by patients than by controls. Manual inspection of the transcripts revealed that aphasic patients were likely to use extended chains of statements linked together by "and", while normal subjects used alternative structures.

Control subjects were more likely to use the appearance indicators "appears" or "looks", which in nearly all instances occurred in constructions such as "The man appears to be …" or "It looks like there is…" This usage difference may indicate simply that aphasic patients were more likely to leave out words that were not strictly necessary, as discussed above; alternatively, perhaps this indicates a more complex phenomenon of normal subjects intentionally distancing themselves from the content of the paintings.

This study was limited in that there was a small number of subjects, and a fairly small text sample for each. The data did not exactly meet conditions for certain statistical techniques used. There were also some inconsistencies in transcription techniques, and inherently subjective components in content-unit grading and category assignment. However, as a pilot study, this work demonstrated that word-use differences between patients and controls are quantitatively identifiable.

This project's chief promise lies in its potential clinical applications. A methodology similar to the one I developed here could be used to create a diagnostic tool. If such a word analysis technique were applied to a large corpus of "well-recovered" aphasic speech, it could yield patterns of word use more consistent with discourse difficulties than with a normal condition. Patients' speech samples could then be automatically scanned for such patterns. Such a test would be easy, quick, and inexpensive to administer, objective, and, if based on a large enough corpus, quite accurate. In addition, learning more about the brain areas associated with unusual use patterns could allow tailoring of treatments to a patient's specific difficulties, and prediction of future problems that a patient might encounter. In particular, the link between speech deficits and impairments in brain areas related to higher-level cognitive tasks suggests that work on higher cognitive tasks could be a promising approach for treating discourse impairments.

REFERENCES

1. Lloyd-Jones D, Adams R, Carnethon M, et al. Heart disease and stroke statistics--2009 update: a report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Circulation. 2009;119(3):e21-181.
2. Pedersen PM, Jørgensen HS, Nakayama H, Raaschou HO, Olsen TS. Aphasia in acute stroke: incidence, determinants, and recovery. Ann Neurol. 1995;38(4):659-66.
3. Naeser MA, Martin PI, Nicholas M, et al. Improved naming after TMS treatments in a chronic, global aphasia patient--case report. Neurocase. 2005;11(3):182-93.
4. Coelho C. Direct attention training as a treatment for reading impairment in mild aphasia. Aphasiology. 2005;19(3-5):275-283.
5. Kimura D. Acquisition of a motor skill after left-hemisphere damage. Brain. 1977;100(3):527-42.
6. Dronkers NF, Wilkins DP, Van valin RD, Redfern BB, Jaeger JJ. Lesion analysis of the brain areas involved in language comprehension. Cognition. 2004;92(1-2):145-77.
7. Lazar RM, Antoniello D. Variability in recovery from aphsasia. Curr Neurol Neurosci Rep. 2008;8(6):497-502.
8. Shewan CM, Kertesz A. Reliability and validity characteristics of the Western Aphasia Battery (WAB). J Speech Hear Disord. 1980;45(3):308-24.
9. Crary MA, Gonzalez Rothi LJ. Predicting the Western Aphasia Battery Aphasia Quotient. J Speech Hear Disord. 1989;54(2):163-6.
10. Wright HH. Discourse in aphasia: An introduction to current research and future directions. Aphasiology. 2011;25(11):1283-1285.13.
11. Huettel SA, Song AW, McCarthy G. Functional Magnetic Resonance Imaging. W.H. Freeman; 2009.
12. Bates E, Wilson SM, Saygin AP, et al. Voxel-based lesion-symptom mapping. Nat Neurosci. 2003;6(5):448-50.
13. Yorkston KM, Beukelman DR. An analysis of connected speech samples of aphasic and normal speakers. J Speech Hear Disord. 1980;45(1):27-36.
14. Bonner MF, Price AR. Where is the anterior temporal lobe and what does it do?. J Neurosci. 2013;33(10):4213-5.
15. De Zubicaray G, Mcmahon K, Eastburn M, Pringle A. Top-down influences on lexical selection during spoken word production: A 4T fMRI investigation of refractory effects in picture naming. Hum Brain Mapp. 2006;27(11):864-73.
16. Packard MG, Knowlton BJ. Learning and memory functions of the Basal Ganglia. Annu Rev Neurosci. 2002;25:563-93.
17. Menon V, Anagnoson RT, Glover GH, Pfefferbaum A. Basal ganglia involvement in memory-guided movement sequencing. Neuroreport. 2000;11(16):3641-5.
18. Newhart M, Trupe LA, Gomez Y, et al. Asyntactic comprehension, working memory, and acute ischemia in Broca's area versus angular gyrus. Cortex. 2012;48(10):1288-97.
19. Rämä P, Courtney SM. Functional topography of working memory for face or voice identity. Neuroimage. 2005;24(1):224-34.
20. Georgopoulos AP, Caminiti R, Kalaska JF. Static spatial effects in motor cortex and area 5: quantitative relations in a two-dimensional space. Exp Brain Res. 1984;54(3):446-54.
21. Duffy JR. Motor Speech Disorders, Substrates, Differential Diagnosis, and Management. Elsevier Health Sciences; 2012.
22. Nixon P, Lazarova J, Hodinott-Hill I, Gough P, Passingham R. The inferior frontal gyrus and phonological processing: an investigation using rTMS. J Cogn Neurosci. 2004;16(2):289-300.
23. Yamasaki H, Labar KS, Mccarthy G. Dissociable prefrontal brain systems for attention and emotion. Proc Natl Acad Sci USA. 2002;99(17):11447-51.
24. Olesen PJ, Westerberg H, Klingberg T. Increased prefrontal and parietal activity after training of working memory. Nat Neurosci. 2004;7(1):75-9.
25. Simonyan K, Horwitz B. Laryngeal motor cortex and control of speech in humans. Neuroscientist. 2011;17(2):197-208.