Although substantial evidence suggests that language impairment in aphasia directly reflects the neuroanatomical damage to the language system, it is important to consider that aphasic errors may also reflect the system's attempt to compensate for its damaged components. Goldstein (1942) was among the first to advocate that disordered language behaviors were not merely a reflection of neurological damage, but the 'struggle of the organism with the defect.' This 'struggle' is reflective of the fact that neurological damage does not occur to a static system, but to a dynamic one that is plastic, active, and capable of reorganization. Thus, language processing in aphasia is not simply a reflection of a damaged language system, but also a manifestation of neurocognitive compensation. Therefore, the study of aphasia not only provides evidence to clarify the brain-language relationship in normal persons, but also provides a window into understanding how the brain attempts to restore a damaged cognitive system.

The purpose of this study was to investigate common brain activity associated with naming errors in a group of persons with chronic aphasia. Just as correct naming tends to recruit relatively consistent brain areas across normal participants, there may also be commonalities in neural recruitment associated with naming errors in aphasia. Although aphasic patients vary considerably based on various factors such as lesion location and extent, it is possible that their errors are rooted in the same functional anatomy. Therefore, this research sought to answer whether patients with different types and severities of aphasia recruit similar cortical areas when they produce semantic or phonemic paraphasias.

Methods

Participants

Twelve persons (7 males) with chronic stroke-induced aphasia were included in this study (Table 1). The mean age was 58.8 years (SD = 14.7) with a range of 45 years. All participants were at least ten-months post-onset, and all but one (P5) were retired at the time of the study. To explore variability as well commonalities in brain activation associated with naming in aphasia, persons with a wide range of aphasia severity were tested. Aphasia assessment employing the Western Aphasia Battery (WAB; Kertesz, 1982) revealed a wide range of language impairment – six participants presented with non-fluent aphasia and six presented with fluent aphasia (Table 1).

Neuroimaging

For the purpose of lesion analyses and the anatomical reference for the fMRI activation maps, all participants underwent high-resolution T1-MRI. The fMRI data collection utilized sparse acquisition of echo planar gradient-echo imaging (EPI).

The fMRI task consisted of naming pictures of high-frequency common nouns (Snodgrass & Vandewart, 1980). During a 20-minute fMRI run, 80 pictures were presented in color on a back-projected mirror situated on top of the head coil. To establish a comparative fMRI baseline, 40 abstract color pictures were presented at random among the 80 real object pictures. Participants were instructed to name aloud every picture on the screen and to say nothing when the abstract pictures were presented. A non-ferrous microphone placed 1-3 cm from participants' mouth was used to record naming attempts which were later scored off-line.

Statistical analyses

The fMRI analysis utilized the FMRIB Software Library (FSL; Smith et al., 2004). The first level analysis (where data from each individual are analyzed separately) was carried out using FMRI Expert Analysis Tool Version 5.4, part of FSL. A timing vector was created for different naming errors for each participant. Thus, brain activity associated with a specific error type was analyzed separately in the first level analysis.

The higher-level analysis (where data from all participants are combined in one analysis) was carried out using a two-stage local analysis of mixed effects (Beckmann, Jenkinson, & Smith, 2003). Similar to the first level analysis, the Z (Gaussianised T/F) statistic images were generated using a cluster threshold of $Z > 2.3$ and a (corrected) cluster significance threshold of $P = 0.05$ (Worsley et al., 1992).

Brain activity during correct naming was estimated by combining the first-level statistical maps associated with correct naming by each participant. To assess activity related to the productions of paraphasias, higher level contrasts were created by comparing statistical maps associated with correct naming to those associated with phonemic and semantic paraphasias.

Results

Task performance

As expected, performance on the naming task varied greatly among the participants (Table 2). Correct naming ranged from 0 to 82.5%, and most participants made errors categorized as phonemic or semantic paraphasias. The distribution of errors across the other categories varied, but very few mixed paraphasias and unrelated responses were recorded. Compared to the rest of the participants, P2 (non-fluent) demonstrated exceptionally poor performance on the naming task and was unable to name a single picture during scanning. Consequently, his data were not included in the higher level fMRI analysis. Both groups produced a similar percentage of phonemic and semantic errors in spite of their ability to correctly name pictures.

Brain activity

The fMRI analysis revealed widespread cortical activation associated with correct naming across the eleven participants included in the higher level group analysis. Much of the activity associated with correct naming compared to incorrect naming attempts was revealed in bilateral medial cortical areas, with no common recruitment noted in the right hemisphere homologues of the classical language areas (Figure 1). Local maxima (voxels with the highest values in a given cluster of activity) were recorded in the bilateral thalamus, cingulate gyrus, and lingual gyrus (Table 3). Bilateral activity was also noted in the caudate nucleus.

Compared to neural recruitment associated with correct naming, greater cortical activity was noted in distinct cortical areas during the production of phonemic and semantic paraphasias (Figure 1). The productions of phonemic paraphasias recruited the cuneus and precuneus (BA 7 and BA 19) in the left, superior, medial parietal lobe, and the superior occipital lobe (Figure 1; Table 3) as well as the posterior angular gyrus (BA 39) of the inferior parietal lobe. Far more extensive brain activity was associated with semantic paraphasias. This activity was revealed in the bilateral, inferior temporal poles

(BA 38), fusiform gyri (BA 19 and BA 37), and basal ganglia as well as the left inferior and middle frontal gyrus (BA 47 and BA 11) compared to correct naming (Figure 1).

Discussion

Our findings suggest common cortical activation associated with correct naming as well as the productions of phonemic and semantic paraphasias in participants with fluent and non-fluent aphasia. It is of particular interest that greatest common activity associated with phonemic paraphasias was found in the perilesional areas of the left parietal lobe, a region which is though to play a crucial role in phonological processing (Sweet et al., 2007). Widespread brain activation is commonly seen when normal participants complete semantic tasks involving a variety of semantic categories (e.g. . Thus, the common cortical network activated during the productions of semantic paraphasias in the current study probably reflects a partially intact semantic network. We are not aware of any other studies that have demonstrated that particular naming errors are associated with common cortical activation across aphasia type and severity. Along the lines of Goldstein's postulations, it is possible that these patterns of brain activity may not represent maladaptation to brain damage; instead, they may reflect the "struggle" of the "organism" to cope with a damaged language network.

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Table 1. Biographical information and testing results for each participant. The time post-onset of stroke is measured in months. All participants are now retired with the exception of P5.

	Biographical information				Test results				Lesion description	
P	Sex	Age	Post-onset	Occupation	WAB: Fluency	WAB: Aud. comp.	WAB: AQ	BNT	Size (cc^3)	Lesion location
1	F	33	17	Accountant	2	6.9	31.8 Broca's	0	34.95	White matter damage deep to BA 6 and 44 and the anterior and middle insula. The arcuate fasciculus is completely severed and the lateral portion of the putamen is involved.
2	M	70	216	Army	1	4.35	34.1 Broca's	3	247.3	Entire MCA distribution including white matter underlying the major cortical language areas
3	M	63	101	Minister	4	5.85	47.1 Broca's	3	342.2	Entire MCA distribution and portions of the anterior medial frontal lobe – basal ganglia involvement
4	M	78	47	Surveyor	2	8.1	47.6 TMA	2	23.48	Posterior middle and superior temporal lobe including BA 37, 22, and 42. Basal ganglia and thalamus involved.
5	F	43	49	House cleaner	4	8.05	50.7 Broca's	13	56.76	Complete destruction of Broca's area (BA 44 & 45) and middle and inferior portions of BA 6; involvement of middle and inferior parietal lobule (BA 40) and superior temporal lobe (BA 22 and 42); BA 4 is intact
6	M	58	43	Teacher	4	9.7	71.6 Broca's	8	87.42	Complete destruction of BA 44, 45, anterior portion of BA 38 including the middle and anterior insula; BAs 1, 2, 3, & 4 are intact
7	F	41	39	Factory worker	6	8	74.4 Anomic	38	145.9	Mostly posterior damage including the middle and superior temporal lobe (BA 22 & 42) as well as middle and inferior parietal lobes (BA 40)
8	M	74	18	Adjustor	8	8.85	81.9 Anomic	31	19.35	Middle and superior temporal lobe involving portions of BA 37, 21, 22, and 39.
9	F	71	10	School assistant	8	8.95	83.9 Anomic	38	18.4	Temporal lobe damage including BA 21 and 22. White matter damage deep in the middle and superior parietal lobe.
10	M	51	47	Cook	7	8.25	84.3 Anomic	41	23.57	BA 22, 42, 39 and posterior portion of BA 38; inferior and middle parietal lobule (BA 40)
11	F	71	18	Secretary	8	9.5	89.4 Anomic	38	8.9	BA 22 partially involved; superior horn of BA 44 and 45 included; complete destruction of the medial BA 6
12	M	52	25	Truck driver	9	9.95	91.5 Anomic	45	3.04	White matter damage underlying the superior portion of BA 44 and BA 6

Table 2. Proportional distribution of naming attempts by each participant

	1	2	3	4	5	6	7	8	9	10	11	12
Correct	1.28	0	37.50	2.56	28.75	26.25	63.75	53.75	82.50	57.50	52.50	67.95
Semantic	2.56	0	23.75	7.69	6.25	5.00	8.75	13.75	7.50	5.00	8.75	10.26
Phonemic	15.38	0	6.25	1.28	12.50	47.50	22.50	10.00	7.50	28.75	15.00	7.69
Mixed	8.97	0	5.00	0.00	5.00	7.50	0.00	0.00	0.00	5.00	1.25	0.00
Unrelated	1.28	0	8.75	43.59	1.25	3.75	0.00	2.50	7.52	0.00	1.25	3.85
Neologism	35.90	0	2.50	19.23	0.00	6.25	0.00	2.50	0.00	1.25	5.00	0.00
Non-Response	34.62	100	16.25	25.64	46.25	3.75	5.00	17.50	1.52	2.50	16.25	10.26

Table 3. Standard coordinates for local maxima where cortical activity was associated with correct naming (top) as well as for the contrasts ‘phonemic errors > correct naming’ (middle) and ‘semantic errors > correct naming’ (bottom).

Correct Naming						
Z*	**x**	**y**	**z**	**Hemisphere**	**Location**	**BA[&]**
3.98	-6	-14	-4	Left	Thalamus	*
3.89	6	26	32	Right	Cingulate Gyrus	32
3.83	-6	30	26	Left	Anterior Cingulate	32
3.69	-6	-20	0	Left	Thalamus	*
3.44	14	-76	2	Right	Lingual Gyrus	18
3.35	12	-84	2	Right	Lingual Gyrus	17
Phonemic Errors > Correct Naming						
3.78	-24	-86	46	Left	Precuneus	19
3.77	-24	-88	42	Left	Cuneus	19
3.73	-24	-80	46	Left	Precuneus	7
3.67	-20	-80	48	Left	Precuneus	7
2.49	-44	-72	44	Left	Angular Gyrus	39
Semantic Errors > Correct Naming						
4.6	-20	18	-14	Left	Inferior Frontal Gyrus	47
4.38	-12	12	2	Left	Caudate	*
4.35	-14	8	6	Left	Putamen	*
4.32	-38	46	-14	Left	Middle Frontal Gyrus	11
4.25	-34	54	-14	Left	Middle Frontal Gyrus	11
3.63	-53	21	-12	Left	Temporal Pole	38
3.58	28	-46	-4	Right	Parahippocampal Gyrus	19
3.5	28	-58	-12	Right	Fusiform Gyrus	19
3.46	39	22	-32	Right	Temporal Pole	38
3.39	28	-44	-12	Right	Fusiform Gyrus	37
3.36	-22	-66	-12	Left	Fusiform Gyrus	19

* Highest Z-value for a voxel within a given cluster of activation

[&] BA = Brodmann’s area

Figure 1. Brain activity associated with 'correct naming > errors' (red color scale) as well as for the contrasts 'phonemic errors > correct naming' (blue scale) and 'semantic errors > correct naming' (green scale). The gradient of the color scale represents Z-scores compared to baseline. An overlay map where the lesions from all participants are combined in one image is shown in grayscale. Lighted shades of gray depict more lesion overlap among particpants.