PREDICTORS OF VERBAL FLUENCY PERFORMANCE IN PERISYLVIAN APHASIA

By

GABRIELLE ELIZABETH GOEHRING

A Thesis Submitted to The W.A. Franke Honors College

In Partial Fulfillment of the bachelor's degree
With Honors in

Biology

THE UNIVERSITY OF ARIZONA

M A Y 2 0 2 3

Approved by:

Dr. Aneta Kielar
Department of Speech, Language, and Hearing Sciences

ABSTRACT

Individuals who struggle with the ability to communicate may be suffering from a language disorder known as aphasia. Verbal fluency in individuals with post-stroke aphasia is a focus of this study. This type of aphasia is caused by damage to the perisylvian region of the brain, which is responsible for language. This study specifically examines how verbal fluency performance is affected in these individuals. Two types of verbal fluency tasks were conducted to examine word processing and fluency performance of stroke participants. The findings were then compared to that of neurotypical controls. One task assessed letter (F-A-S) fluency, while the other task looked at category (animal) fluency. The data extracted from these tasks allowed us to generate fluency scores for each individual and analyze psycholinguistic properties of words produced. Cognitive and language measures were also used to predict fluency scores. The main goal was to investigate how individuals with aphasia perform on letter fluency tasks compared to healthy older adults. Our results indicated that psycholinguistic word properties influenced letter fluency performance, but not category fluency. It was also found that language and cognitive measures related to phonological skill predict fluency performance. Overall, the results suggest that individuals with perisylvian post-stroke aphasia demonstrate impairment on phonological code retrieval.

Key Words: post-stroke aphasia, predictors, verbal fluency, psycholinguistic properties, cognitive and language measures

INTRODUCTION

Aphasia is an acquired language disorder characterized by impairment in comprehension and/or expression of spoken and/or written language. The most common etiology of aphasia is cerebrovascular accident, commonly referred to as stroke, to the middle cerebral artery, causing lesion to the perisylvian region (Na et al., 2022). Individuals with aphasia experience damage to areas of the brain associated with language, thereby affecting comprehension and production of language. There are several different types of aphasia, determined by the nature of language symptoms that may correlate with location of the brain regions that are impacted by the lesion. The types of aphasia include the following: anomic aphasia, Broca's aphasia, conduction aphasia, Wernicke's aphasia, transcortical motor aphasia, global aphasia, transcortical sensory aphasia, and mixed transcortical aphasia.

Anomic aphasia is a type of aphasia that is characterized by marked word finding difficulties in the context of relatively spared repetition, comprehension, and fluency (Sheppard & Sebastian, 2022). It is usually the least severe form. As individuals recover Broca's or Wernicke's aphasia can evolve into anomic presentation. Speech is fluent with good auditory comprehension but poor lexical retrieval (Fridriksson et al., 2018). Anomic aphasia results from lesions located in the left perisylvian regions, including subcortical regions (Sheppard & Sebastian, 2022). Broca's aphasia is characterized by non-fluent speech marked by grammatical and syntactic errors (Sheppard & Sebastian, 2022). In Broca's aphasia, lesions are often located in the left inferior frontal brain regions that support speech production and grammatical processing (Sathian & Crosson, 2015). It is also referred to as "expressive aphasia" because language production can be slow and effortful (Sheppard & Sebastian, 2022). Individuals with conduction aphasia have difficulty with holding verbal information in working memory leading to phonological paraphasias (Le & Lui, 2022). Repetition is impaired, and comprehension and expression of speech can also be affected (Sheppard & Sebastian, 2022). Conduction aphasia results from damage to the white matter tract that connects Wernicke's area to Broca's area known as the arcuate fasciculus (Sheppard & Sebastian, 2022). Wernicke's aphasia is also termed "receptive aphasia," and is characterized by comprehension, naming, and repetition impairments (Sheppard & Sebastian, 2022). Speech is fluent, but individuals have difficulty with sentence constructions and produce paraphasia and neologisms (Sheppard & Sebastian, 2022). Lesions are located near the temporal and parietal regions of the brain, with damage to Wernicke's area, which is the center for comprehension and planning of words (Le & Lui, 2022). Transcortical motor aphasia results in non-fluent speech but individuals still have intact repetition skills of complex phrases (Le & Lui, 2022). Individuals have difficulty with initiating speech and can present echolalia (Sheppard & Sebastian, 2022). Lesions are located in the medial frontal cortex and the presupplementary motor area, near Broca's area (Sheppard & Sebastian, 2022). Global aphasia leads to loss of speech production and comprehension that result from large lesions to the whole perisylvian cortex. It is the most severe form and individuals have difficulty with all aspects of language (Sheppard & Sebastian, 2022). They often experience loss of the ability to use language due to the stroke. They may have difficulty understanding spoken/written language and can only produce a few words (Le & Lui, 2022). These large left hemisphere lesions commonly affect both Broca's area and Wernicke's areas (Sheppard & Sebastian, 2022). Transcortical sensory aphasia is characterized by difficulties in comprehension that manifest as semantic paraphasia, but speech production is usually preserved (Le & Lui, 2022). Individuals have intact repetition skills (Sheppard & Sebastian, 2022). This type of aphasia associates with lesions located near Wernicke's area, between the areas of the middle cerebral artery and the posterior cerebral artery (Sheppard & Sebastian, 2022). Those with mixed transcortical aphasia have repetition skills but display speaking and comprehension impairment (Sheppard & Sebastian, 2022). The associated lesions are large and located near Wernicke's area and Broca's area. These regions of the brain are spared, but language recognition and production are isolated and generated from other areas (Sheppard & Sebastian, 2022). A hallmark characteristic of all aphasias, regardless of subtype, is anomia. Anomia can be defined as having difficulty with word retrieval (Fridriksson et al., 2005).

Anomia can be assessed using confrontation naming tasks and verbal fluency tasks. Verbal fluency is a measure of lexical retrieval and word finding that is infrequently used to evaluate anomia in aphasia. It is less common compared to confrontation naming, however, this task can provide important information about lexical abilities because it relies on generation, where the individual has to generate words on their own. There are two common tasks of verbal fluency tests. These include *letter and category fluency tasks*.

Letter fluency tasks require an individual to generate words that begin with a certain letter of the alphabet. This type of fluency task is related to phonology or executive control processes (Van den Berg et al., 2022). Category fluency requires generation of words that belong to the target category (i.e., animals). Performance on the category fluency task is associated with ability to retrieve information from semantic memory (Van den Berg et al., 2022). Semantic fluency draws on the arrangement of our mental lexicon and on existing semantic links (Bose et al., 2022). In contrast, letter fluency tasks rely on inhibition of semantic processes (Bose et al., 2022). Verbal fluency tasks have been universally used in research as well as in clinical practices. Evidence suggests that individuals with aphasia tend to generate fewer responses during trials compared to those who are neurotypical, demonstrating impaired performance (Bose et al., 2022).

This study examines psycholinguistic properties based on the words generated by participants during verbal fluency tasks. These variables are representative of the language abilities of an individual. They can be used to indicate language impairment resulting from damage to the left hemisphere regions of the brain. Psycholinguistic properties are helpful in identifying the specific difficulties an individual experiences with language (Rofes et al., 2019). It is necessary to distinguish the kind of impairment involved with language and determine how it contrasts the processes of healthy individuals. Analysis of psycholinguistic properties can aid in understanding verbal fluency impairments. They are informative about neural disorders and hold educational and predictive value, which may assist in the referral to more specialized services for individuals with aphasia (Rofes et al., 2019). For example, these fluency performance measures can be used to predict features of lexical simplification, word difficulty, and vocabulary knowledge (Ehara, 2017).

The psycholinguistic properties that this study focused on include age of acquisition, frequency, familiarity, imageability, arousal, valence, phonological neighborhood, phonological length, orthographic length, and semantic neighborhood. Age of acquisition ratings reflect the age of when a person acquired a certain word (Ehara, 2017). Words acquired earlier in life show to be more accessible to those with aphasia compared to words learned later on (Brysbaert & Ellis, 2016). Frequency describes recurrence, or how many times a word is used within a collection of speech (Fyndanis et al., 2017). Familiarity refers to how commonly a word appears in one’s daily vocabulary (Ehara, 2017). Words that are high in imageability easily evoke a mental image or sensory experience (Tóth et al., 2022). Arousal is the strength of the emotion that a word provokes, this value can be high or low (Loveridge, 2022). Valence rates indicate the subjective value of a word that provokes an emotional stimulus (Loveridge, 2022). This means that words can have either a positive, negative, or neutral effect on an individual. For example, “happiness” has a positive valence, while “suffering” has a negative valence. Phonological neighborhood is the number of words that can be generated by varying only one phoneme while keeping the phonological identity of the word the same (Alyahya et al., 2020). Phonological length is the number of phonemes in a word (Balota et al., 2007). Orthographic length is the number of letters in a word. Semantic neighborhood is a variable that measures global co-occurrence, referring to the variation in distribution of semantic neighbors in a word’s space (Danguecan & Buchanan, 2016). Psycholinguistic properties are valuable to analyze the words generated during the experimental tests. Particular to this study, the verbal fluency tasks, also known as generative naming tasks, were used to examine these variables, and this examination will show new insights on the differences in verbal fluency between individuals with chronic post-stroke aphasia and neurotypical adults.

The Current Study

The purpose of this study is to understand the differences in psycholinguistic properties of words produced by individuals with chronic post-stroke aphasia compared with age- and education- matched unimpaired controls. It is also to understand what contributes to these differences of word retrieval in individuals with post-stroke aphasia. Knowing this information about how individuals with aphasia process language can be helpful in designing treatments. To accomplish this goal, we conducted a retrospective analysis of data collected by the Language and Neuroimaging Research Laboratory at the University of Arizona.

METHODS

Participants

Thirty-eight individuals participated in the study. Twelve of these participants had chronic post-stroke aphasia and the other twenty-six participants were neurotypical controls. Participants with aphasia we diagnosed by the Speech-Language Pathologist or neurologist. The two groups of participants were matched for age ($t(36) = 1.31$, $p = 0.198$) and education ($t(36) = 1.48$, $p = 0.154$). Each participant in the study was assigned a study number and all data were de-identified. All individuals were right handed native English speakers (Edinburgh Handedness Inventory, Oldfield, 1971). Pure tone air-conduction thresholds were used to assess the hearing status of the participants. Each individual had adequate vision (normal or corrected-to-normal) and hearing (normal or with personal hearing aid). The tasks were performed in a quiet space with sound amplification, if necessary.

Participants with post-stroke aphasia were recruited from the Aphasia Research Project and the Language and Neuroimaging Research Laboratory at the University of Arizona (UA). They were also recruited from the Speech, Language and Hearing Clinic at UA and from Friends of Aphasia Center in Tucson, Arizona. The age of this group ranged from 27 to 80 years ($M = 58.67$, $SD = 13.32$). The range for years of education was 12 to 18 years ($M = 15.17$, $SD = 2.08$). The inclusion criteria for these individuals included having had experienced a single left hemisphere stroke no less than 6 months prior to the study ($M = 6.72$ years post-onset, $SD = 3.19$ years post-onset). Participants were excluded if they had developmental language disorders, neurological diseases, epilepsy, head trauma, brain surgery, unstable or poor health, and psychiatric disorders. Participants with aphasia were diagnosed by a speech-language pathologist and/or board-certified neurologist. The results of clinical presentation, narrative speech samples, and standardized assessments were used to confirm the presence of aphasia. The type and severity of aphasia was not inclusion criteria for the study. However, administration of the Western Aphasia Battery Bedside Examination (WAB-Bedside, Kertesz, 2007) gave an estimate of aphasia severity and type. These types were classified as conduction (*n* = 1), Broca's aphasia (*n* = 2), anomic (*n* = 6), Wernicke's aphasia (*n* = 1), and transcortical motor (*n* = 1). One participant evolved from Broca's aphasia and was classified as borderline fluent (*n* = 1),Those with significant dysarthria or apraxia of speech and with profuse phonemic paraphasia were excluded from the study. Individuals who participated were able to produce words at 65% accuracy or higher. Three out of all individuals showed mild to moderate apraxia of speech (AOS) based on a motor speech evaluation using Duffy (2005) protocol.

Control participants were unimpaired, healthy volunteers. They were recruited from the community of the University of Arizona and the Tucson region using advertisements approved by the Human Subjects Protection Program (HSPP) at the University of Arizona. Control individuals were neurotypical adults, with no history of developmental or acquired language, neurologic, or psychiatric impairment. None of the control participants were taking neuroleptic or mood-altering medications. Each control participant took part in the same behavioral and neuroimaging assessments that were also completed by those with aphasia. The individuals in the control group scored within normal limits on all standardized cognitive and language tests, including the Montreal Cognitive Assessment (MoCA, Nasreddine et al., 2005; *M* = 26.81, *SD* = 2.24).

Demographics of the stroke aphasia and group means for control participants are included in **Table 1**. These evaluations of each participant were completed in-person over two 2-hour sessions. The assessments were executed on different days within a 2-week time period.

Examples and practice items were given at the beginning of each experimental test to make sure each participant understood the task. **Table 2** presents the scores on language and cognitive assessments from participants with aphasia and unimpaired controls. Study procedures were approved by the UA Institutional Review Board (IRB).

As listed in **Table 2**, to measure auditory processing, tests for Psycholinguistic Assessments of Language Processing in Aphasia (PALPA 1; Kay et al., 1992), PALPA 2 (Kay et al., 1992), and PALPA 15 (Kay et al., 1992) were administered. Only PALPA 15, consisting of rhyme judgment, was significantly impaired in participants with aphasia compared to neurotypical adults. Visual-orthographic recognition was tested using PALPA 18 (Kay et al., 1992) and PALPA 19 (Kay et al., 1992). There was no significant difference between participants with aphasia and unimpaired controls. Orthographic recognition was measured with PALPA 25 (Kay et al., 1992), and performance on this test was significantly more impaired in those with aphasia. Speech production was measured with PALPA 11 (Kay et al., 1992), Children's Nonword Repetition Test (CNRT; Gathercole et al., 1994), and rhyme production (Beeson et al., 2010). Compared to controls, participants with aphasia were impaired only on CNRT. Phonology-orthography transcoding (Arizona Phonological Battery) was assessed using the letter-to-sound (spoken), letter-to-sound (written), read consonant-vowel-consonant (CVC) nonwords (spoken), and spell CVC nonwords (written) assessments (APB; Beeson et al., 2010). Only the spell CVC nonwords (written) test showed that those with aphasia were impaired compared to neurotypical participants. Assessments used to measure phonology (APB) were phoneme segmentation initial (word), phoneme segmentation initial (nonwords), phoneme segmentation final (word), phoneme segmentation final (nonwords), phoneme deletion (words), phoneme deletion (nonwords), phoneme blending (words), phoneme blending (nonwords), phoneme replacement (words), phoneme replacement (nonwords), APB repetition (Beeson et al., 2010). Participants with aphasia performed significantly lower than controls on every one of these tests, excluding phoneme segmentation initial (word), phoneme segmentation initial (nonwords), and APB repetition. Semantic knowledge was tested using the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 2007), the Camel and Cactus Test (Adlam et al., 2010), PALPA 48 (Kay et al., 1992), and PALPA 49 (Kay et al., 1992). Each of these assessments showed significance and that participants with aphasia were more impaired on semantic knowledge than controls. Confrontation naming was measured using the Boston Naming Test (Kaplan et al., 1983), and individuals with aphasia scored significantly lower compared to controls. Generative naming was assessed using the Delis-Kaplan Executive Function System (D-KEFS): Trail Making Test (Delis et al., 2001). This test was also significant and showed impairment for participants with aphasia compared to controls. Reading and writing were measured using (Arizona Battery for Reading and Spelling), read (words), read (nonwords), spell (words), and spell (nonwords) (ABRS; Beeson et al., 2010). Spell (words) and spell (nonwords) assessments showed impairment for individuals with aphasia compared to controls. Sentence comprehension was assessed using the Northwestern Assessment of Verbs and Sentences-Sentence Comprehension Test (NAVS-SCT; Cho-Reyes & Thompson, 2012; Thompson, 2011). Participants with aphasia performed lower on this test compared to controls. Memory/visuo-spatial skills were assessed using Warrington Face Recognition Memory (WFR; Warrington, 1984), digit span forward (Wechsler Adult Intelligence Scale) (WAIS-R; Wechsler, 2008), and digit span backward (WAIS-R) (Wechsler, 2008). Compared to controls, participants with aphasia scored lower on the digit span forward and the digit span backward tests.

Table 1. Demographic characteristics for individuals with stroke aphasia and control participants means.

ID	gender	age	education	TPO (years)	Aphasia type	WAB Bedside Severity	Apraxia Rating
301	F	55	13	7.8	Anomic	83.38	0
302	F	62	12	11.1	Broca's	49.17	0
303	M	54	14	4.1	Anomic	87.5	0
304	M	55	16	9.1	Borderline Fluent	84.17	0
305	M	80	16	3.8	Anomic	89.17	0
306	M	55	14	7.11	Conduction	86.67	0
307	M	27	18	5.1	Broca's	66.67	3
310	M	56	18	7	Wernicke's	55.83	1
311	M	58	14	8	Anomic	90	1
312	M	59	17	1.8	Anomic	87.5	0
313	M	65	17	3.4	Anomic	92.5	0
314	M	78	13	12.3	Transcortical Motor	83.83	0
Stroke							
Mean	2F/10M	58.67	15.17	6.72		79.70	0.42
SD		*13.32*	*2.08*	*3.19*		*14.31*	*0.90*
Control							
Mean	17F/9M	64.04	16.31	NA			
SD		*10.99*	*2.31*	*NA*			

TPO: time post-onset

Table 2. Language and cognitive scores for participants with aphasia (*n* = 12) and controls (*n* = 26) in percent correct (unless indicated otherwise).

	Aphasia		Controls			
	M	**SD**	**M**	**SD**	**F**	***p-value***
Auditory Processing						
Minimal pairs words (PALPA 1 & 2)	96.36	5.95	99.00	2.04	6.69	*.180*
Minimal pairs nonwords (PALPA 1 & 2)	91.82	11.89	98.80	3.32	25.01	*.083*
Rhyme judgement (PALPA 15)	91.25	10.14	97.89	3.85	12.56	***.048***
Visual-Orthographic Recognition						
Letter reversal: PALPA 18	98.84	1.43	98.56	2.14	2.82	*.677*
Case matching: upper to lower PALPA 19	99.36	1.50	99.85	.77	7.38	*.306*
Orthographic Recognition (Words)						
Visual lexical decision: PALPA 25	93.44	7.18	98.60	1.96	9.34	***.031***
Speech Production						
Repeat words: PALPA 11	95.08	6.88	98.84	1.87	16.43	*.200*
Repeat nonwords: CNRT	67.96	21.73	92.79	7.01	26.91	***.004***
Rhyme production	76.67	36.27	99.13	2.88	22.13	*.055*
Phonology-Orthography Transcoding (APB)						
Letter-to-sound (spoken)	85.00	23.35	99.40	1.66	14.95	*.068*
Letter-to-sound (written)	81.36	31.87	98.33	4.58	24.26	*.109*
Read CVC nonwords (spoken)	78.18	28.92	97.40	3.57	12.98	*.052*
Spell CVC nonwords (written)	39.09	34.70	94.42	6.98	46.51	***<.001***
Phonology (APB)						
Phoneme segmentation initial (word)	81.67	32.71	99.13	2.88	20.63	*.092*
Phoneme segmentation initial (nonwords)	76.67	38.46	98.70	3.44	51.40	*.073*
Phoneme segmentation final (word)	72.73	37.97	99.57	2.09	34.40	***.041***
Phoneme segmentation final (nonwords)	66.36	38.80	98.70	3.44	52.24	***.020***
Phoneme deletion (words)	69.09	31.77	100.00	.000	49.96	***.009***
Phoneme deletion (nonwords)	66.00	32.73	100.00	.000	43.28	***.009***
Phoneme blending (words)	41.67	32.43	89.23	12.63	18.74	***<.001***
Phoneme blending (nonwords)	32.50	30.19	88.85	13.95	19.67	***<.001***
Phoneme replacement (words)	35.15	36.40	91.03	9.42	44.86	***<.001***
Phoneme replacement (nonwords)	27.88	36.49	87.69	14.93	15.38	***<.001***
APB Repetition	89.98	23.30	99.59	0.76	12.25	.181
Semantic Knowledge						
Peabody Picture Vocabulary Test	89.55	4.34	96.14	2.83	7.50	***<.001***
Camel and Cactus Test	78.13	6.96	91.29	3.00	5.84	***<.001***
Written word-picture match: PALPA 48	90.91	8.89	99.58	.95	30.17	***.009***
Auditory synonym judgment: PALPA 49	85.00	8.03	96.60	4.35	5.53	***<.001***

Confrontation Naming						
Boston Naming Test	69.03	24.35	94.42	6.56	37.14	***.004***
Generative Naming						
D-KEFS: Trail Making Test	67.33	34.44	91.50	14.34	23.64	***.045***
Reading and Writing (ABRS)						
Read words (8 participants)	86.88	28.18	99.69	.84	16.06	*.239*
Read nonwords (7 participants)	73.57	34.49	98.70	3.44	18.41	*.102*
Spell words (6 participants)	61.67	30.44	98.23	3.17	18.89	***.032***
Spell nonwords (6 participants)	35.00	33.17	90.87	7.78	20.82	***.009***
Sentence Comprehension (SCT)						
NAVS-SCT	83.64	15.38	99.62	1.09	53.62	***.006***
Memory/Visuo-Spatial Skills						
Episodic memory: Face Recognition (WFR)	74.80	7.38	78.08	7.14	.007	*.230*
Digit span forward (WAIS-IV)[a]	5.40	2.07	11.60	1.92	.005	***<.001***
Digit span backward (WAIS-IV)[a]	3.80	2.35	9.76	2.59	.601	***<.001***

APB is Arizona Phonological Battery (Beeson et al., 2010); ABRS is Arizona Battery for Reading and Spelling (Beeson et al., 2010); PALPA is Psycholinguistic Assessments of Language Processing in Aphasia (Kay et al., 1992); NAVS-SCT = Northwestern Assessment of Verbs and Sentences-Sentence Comprehension Test (Cho-Reyes & Thompson, 2012; Thompson, 2011); Children's Nonword Repetition Test (CNRT; Gathercole et al., 1994); D-KEFS: Delis-Kaplan Executive Function System (Delis et al., 2001); Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 2007); Camel and Cactus Test (Adlam et al., 2010); Boston Naming Test (Kaplan et al., 1983); WFR is Warrington Face Recognition Memory Test (Warrington, 1984). [a]WAIS-R Wechsler Adult Intelligence Scale (Wechsler, 2008), Digit Span total raw score out of 16.

Experimental Tests: Verbal Fluency Tasks

Two separate tests were administered to each participant, one assessing letter fluency and the other assessing category (animal) fluency. The individuals were instructed to produce as many words as possible that fit the pre-specified criteria. For the category fluency task, participants were asked to name as many animals as possible in one minute. For the letter fluency task, participants were given one minute to produce as many words as possible starting with letters "F", "A", "S" in separate trials. The category and letter fluency tasks were administered to each participant in the same order within the same session. The words produced from these tests were used to calculate fluency scores and derive dependent variables used in this study.

The assessment of the responses from participants followed a scoring criteria established in the Delis-Kaplan Executive Function System (D-KEFS) test. Words were scored as correct if they started with the target letter, were a member of the target category, were contractions (e.g. aren't), slang words or swear words, compound words (e.g. real estate), proper nouns that are not people/places (e.g. Saturday, June), and if the word could be either a common noun or the name of a person/a number (e.g. frank, for), unless it was clarified that the word is a name/number.

Words were scored as incorrect if they had been repeated, did not start with the correct letter, or were not a member of the target category. Other words excluded from correct scoring were proper nouns, specifically people/places (e.g. Arizona, John), numbers with numerical meanings (e.g. thirteen), grammatical variants that do not have substantially different meanings (e.g. weak, weaker, weakest), words changed to the past tense (e.g. jump, jumped), words formed by changing the number of a noun (e.g. monkey, monkeys), or words that are not real. These were identified as "set-loss errors." These criteria were followed for both letter and category fluency tasks.

The scoring criteria for category (animal) fluency required additional guidelines for correct answers. Words scored as correct included synonyms (e.g. pig/swine, rooster/hen), subordinate categories (e.g. mammals, insects), names that represent genders of the same animal (e.g. cow, bull), words that refer to the same animals at different stages (e.g. puppy, dog), and words of two or more variations within the same species/different breeds of an animal (e.g. parrot, dove, crow, etc.). The following categories were excluded: duplicated words, derived words (e.g. kitten, kitty), adjectives provided alone/with the name of the target category (e.g.

poisonous, poisonous snake), adjectives used to describe attributes of the same member (e.g. lion, little lion), and words that are ordinate/superordinate (e.g. animal, living things).

Assessment of Psycholinguistic Properties

Data regarding psycholinguistic properties were collected from the South Carolina Metabase (SCOPE), a repository of databases, to obtain variable values provided from the list of correct words each individual produced (Gao et al., 2022). Values for thirteen variables were generated using the database for each correct word produced by the participant. The words per task of each participant were entered into the SCOPE database separately at a time. The psycholinguistic properties included the following: age of acquisition (Kuperman et al., 2012), frequency (SUBTLEX-US, Brysbaert & New, 2009), familiarity (Scott et al., 2019), imageability (Scott et al., 2019), arousal (NRC, Mohammad & Turney, 2010), valence (NRC, Mohammad & Turney, 2010), semantic neighborhood (HiDEx, Shaoul & Westbury, 2006), phonological neighborhood (ELP, Balota et al., 2007), orthographic length, and phonological length (ELP, Balota et al., 2007). After extracting the values for each correct word, each property was averaged into a single value for each individual participant per task. The data were recorded separately for letter fluency and for category fluency.

Statistical Analyses

Statistical analyses were performed using IBM SPSS Statistics Version 28.0. The data was imported into the software to compare the two groups of participants. First, age and education were matched by comparing means using an independent sample t-test. The same type of test was done to compare each of the thirteen word properties between the groups of post-stroke aphasia and control participants for the two verbal fluency tasks. The results for the between-group comparison of word properties for letter fluency are included in **Table 3**, and the results of category fluency are included in **Table 4**. Statistical significance of each psycholinguistic property for both letter and category fluency were analyzed for comparisons. The p-value reported for the Levene's test was used for equality of variances, meaning the significance value dictated whether or not equal variances were assumed for the values produced by the t-test.

Pearson's correlations between psycholinguistic properties were analyzed and are represented for letter fluency in **Table 5** and for category fluency in **Table 7** for stroke participants. Correlation values represented the degree of association between psycholinguistic properties. A series of multiple linear regression analyses were performed to understand the relationships between variables. This included (1) the effects of psycholinguistic properties on letter and category fluency scores and (2) the effects of cognitive abilities on performance on fluency tasks.

RESULTS

Psycholinguistic Properties of Words Produced on Verbal Fluency Tasks

Independent samples t-tests were used to compare the psycholinguistic properties of words produced between individuals with aphasia and neurotypical adults. In **Table 3**, we included the psycholinguistic properties of words produced on letter (F-A-S) fluency tasks between post-stroke aphasia and control groups. The difference in the total number of words produced between the groups was significant ($t(14.60) = 8.82$; $p < .001$). This indicates that individuals with aphasia produced fewer words ($M = 13.38$, $SD = 12.68$) compared to controls ($M = 48.58$, $SD = 7.43$). There were also significant differences between the following properties of words produced: age of acquisition ($t(36) = 3.06$; $p = .004$), frequency ($t(36) = -2.92$; $p = .006$), phonological neighborhood ($t(36) = -2.17$; $p = 0.37$), and semantic neighborhood ($t(36) =$ -

3.28; *p* = .002), reflecting that individuals with aphasia produced words with lower age of acquisition (*M* = 6.08, *SD* = 1.67) compared to controls (*M* = 7.31, *SD* = 0.83), words with greater frequency (*M* = 3.23, *SD* = 0.45) compared to controls (*M* = 2.84, *SD* = 0.33), words with more phonological neighbors (*M* = 16.53, *SD* = 8.31) compared to controls (*M* = 12.08, *SD* = 4.43), and words that have more semantic neighbors (*M* = 0.59, *SD* = 0.03) compared to controls (*M* = 0.56, *SD* = 0.03).

The results for the differences in psycholinguistic properties of words produced on category (animal) fluency tasks between individuals with aphasia and controls were included in **Table 4**. The total number of words produced between the two groups was significant (*t*(36) = .71; *p* <.001). This suggests that individuals with aphasia produced fewer words (*M* = 9.58, *SD* = 5.21) compared to controls (*M* = 23.85, *SD* = 5.62). There were no significant differences between the psycholinguistic properties of words produced on category (animal) fluency tasks (**See Table 4**).

Table 3. Psycholinguistic properties in letter (F-A-S) fluency between post-stroke aphasia and control groups.

Psycholinguistic Properties	**Post-stroke aphasia group**	**Control group**	***t***	***df***	***p-value***
Total Number of Words Produced	13.83 ± 12.68	48.58 ± 7.43	**8.82**	**14.60**	**<.001**
Age of Acquisition	6.08 ± 1.67	7.31 ± 0.83	**3.06**	**36**	**.004**
Frequency	3.23 ± 0.45	2.84 ± 0.33	**-2.92**	**36**	**.006**
Familiarity	5.88 ± 0.38	5.82 ± 0.11	-.58	11.90	.427
Imageability	5.28 ± 0.95	4.89 ± 0.42	-1.35	13.01	.202

Arousal	0.47 ± 0.07	0.46 ± 0.04	-.27	36	.791
Valence	0.59 ± 0.11	0.56 ± 0.05	-.95	13.14	.358
Phonological Neighborhood	16.53 ± 8.31	12.08 ± 4.43	**-2.17**	**36**	**.037**
Phonological Length	4.37 ± 1.37	4.62 ± 0.67	.79	36	.437
Orthographic Length	5.29 ± 1.38	5.63 ± 0.71	.99	36	.327
Semantic Neighborhood	0.59 ± 0.03	0.56 ± 0.03	**-3.28**	**36**	**.002**

Values shown are mean ± SD.
Values were extracted from the South Carolina Metabase (SCOPE). Total words are the number or words produced from verbal fluency. Age of acquisition is the age at which a word is acquired. Frequency follows the logarithmic function of base 10, representing how common words are in our daily lives. Familiarity means that a higher value represents a more subjectively familiar word. Imageability is the effort applied to produce a mental image of a concept with a high value signifying more imageable. Arousal indicates a high value means more arousing using the word-emotion association. Valence indicates a high value is more positive and a low value is more negative using word-emotion association. Phonological neighborhood represents how many words can be generated by varying only one phoneme while keeping the identity of the word. Phonological length is the number of phonemes in a word. Semantic neighborhood is the number of semantic neighbors within a distance in co-occurrence space. Orthographic length is the number of letters in a word.

Table 4. Psycholinguistic properties in category (animal) fluency between post-stroke aphasia and control groups.

Psycholinguistic Properties	**Post-stroke aphasia group**	**Control group**	***t***	***df***	***p-value***
Total Number of Words Produced	9.58 ± 5.21	23.85 ± 5.62	**.71**	**36**	**<.001**
Age of Acquisition	5.45 ± 1.58	5.57 ± 0.49	.25	11.98	.728
Frequency	2.60 ± 0.56	2.55 ± 0.17	-.30	11.88	.766
Familiarity	5.59 ± 0.34	5.49 ± 0.20	-.90	13.11	.384
Arousal	0.44 ± 0.07	0.46 ± 0.04	.90	13.78	.383
Valence	0.53 ± 0.05	0.51 ± 0.03	-.87	15.08	.397
Phonological Neighborhood	14.36 ± 6.43	12.36 ± 2.89	-.99	11.74	.342

Phonological Length	4.64 ± 1.05	4.74 ± 0.56	.32	13.93	.754
Orthographic Length	5.44 ± 1.22	5.69 ± 0.59	.65	13.40	.526
Semantic Neighborhood	0.55 ± 0.05	0.54 ± 0.03	-.79	11.98	.447

Values shown are mean ± SD.
Values were extracted from South Carolina Metabase (SCOPE). Total words are the number or words produced from verbal fluency. Age of acquisition is the age at which a word is acquired. Frequency follows the logarithmic function of base 10, representing how common words are in our daily lives. Familiarity means that a higher value represents a more subjectively familiar word. Arousal indicates a high value means more arousing using the word-emotion association. Valence indicates a high value is more positive and a low value is more negative using word-emotion association. Phonological neighborhood represents how many words can be generated by varying only one phoneme while keeping the identity of the word. Phonological length is the number of phonemes in a word. Orthographic length is the number of letters in a word. Semantic neighborhood is the number of semantic neighbors within a distance in co-occurrence space.

Pearson’s Correlations Between Psycholinguistic Properties for Words Produced

Bivariate correlation analyses were performed to examine the relationships between psycholinguistic properties for words produced on verbal fluency tasks for both individuals with aphasia and control participants, individually. **Table 5** reports Pearson's correlations between psycholinguistic properties for words on letter (F-A-S) fluency tasks for individuals with aphasia. There were significant correlations between age of acquisition and frequency (r = -.599), familiarity (r = -.673), imageability (r = -.794), phonological neighborhood (r = -.640), phonological length (r = .903), and orthographic length (r = .898). This means that the earlier in life a word is acquired, the more frequent a word is, the more familiar a word is, the more imageable a word is, the more phonological neighbors a word has, the shorter a word’s phonological length is, and the fewer number of letters a word has. Significant correlations between frequency and phonological neighborhood (r = .740), phonological length (r = -.744), and orthographic length (r = -.783) were reported, such that the more frequently a word is used, the more phonological neighbors the word has, the shorter a word’s phonological length is, and the fewer number of letters a word has. The word property of familiarity had significant correlations to imageability (*r* = .813) and arousal (*r* = -.621), meaning that the more familiar a word is, the more imageable and the less arousing it is. Imageability had a significant negative correlation to arousal (*r* = -.710). If a word is more imageable, it is also less arousing. There were significant correlations between phonological neighborhood and phonological length (*r* = -.814), as well as orthographic length (*r* = -.856). This means the more phonological neighbors a word has, the shorter it is in phonological length and the fewer numbers of letters it has. Phonological length had a significant positive correlation to orthographic length (*r* = .984), so a word that has a greater phonological length usually has more letters in it.

Table 6 reports Pearson's correlations between psycholinguistic properties for words produced on letter (F-A-S) fluency tasks for controls. Age of acquisition had significant correlations to frequency (*r* = -.864), phonological neighborhood (*r* = -.640), phonological length (*r* = .720), semantic neighborhood (*r* = -.674), and orthographic length (*r* = .717). This indicates that words acquired earlier in life are more frequent, have more phonological neighbors, are shorter in phonological length, have more semantic neighbors, and have fewer letters. There were significant correlations between frequency and phonological neighborhood (*r* = .625), phonological length (*r* = -.683), semantic neighborhood (*r* = .820), and orthographic length (*r* = -.659). The more common a word is, the more phonological neighbors it has, the shorter in phonological length it is, the more semantic neighbors it has, and the fewer letters it has. Imageability had a significant negative correlation to arousal (*r* = -.493), so if a word is more imageable, it is also less arousing. Arousal was significantly correlated to valence (*r* = -.407), meaning a word has a negative word-emotion association if it is more arousing. Valence had a significant positive correlation to semantic neighborhood (*r* = .425). This means that a word with a positive word-emotion association has more semantic neighbors. There were significant correlations between phonological neighborhood and phonological length (*r* = -.826), semantic neighborhood (*r* = .441), and orthographic length (*r* = -.817), such that words with more phonological neighbors have a shorter phonological length, more semantic neighbors, and fewer letters. Significant correlations between phonological length and semantic neighborhood (*r* = -.462) and orthographic length (*r* = .976) were reported. If a word is longer in phonological length, it has fewer semantic neighbors but has more letters in it. Semantic neighborhood had a significant negative correlation to orthographic length (*r* = -.443), meaning that a word with more semantic neighbors has a smaller number of letters.

Pearson's correlations between psycholinguistic properties for words produced on category (animal) fluency tasks for stroke participants are shown in **Table 7**. Age of acquisition had significant correlations to frequency (*r* = -.922), familiarity (*r* = -.875), valence (*r* = -.654), phonological neighborhood (*r* = -.769), phonological length (*r* = .832), orthographic length (*r* = .822), and semantic neighborhood (*r* = -.913). This represents that words acquired earlier in life are more frequent, more familiar, have a more positive word-emotion association, have more phonological neighbors, are shorter in phonological length, have fewer letters, and have more semantic neighbors. There were significant correlations between frequency and familiarity (*r* = .898), phonological neighborhood (*r* = .922), phonological length (*r* = -.889), orthographic length (*r* = -.902), and semantic neighborhood (*r* = .971). This means that words used more frequently are more familiar, have more phonological neighbors, have a shorter phonological length, have fewer letters, and have more semantic neighbors. The word property of familiarity had significant correlations to phonological neighborhood (*r* = .737), orthographic length (*r* = -.611), and semantic neighborhood (*r* = .864). If a word is more familiar, it has more phonological neighbors, has fewer letters, and has more semantic neighbors. There were significant correlations between phonological neighborhood and phonological length (*r* = -.908), orthographic length (*r* = -.908), and semantic neighborhood (*r* = .888). Words that have more phonological neighbors, have a shorter phonological length, fewer letters, and more semantic neighbors. Phonological length was significantly correlated to orthographic length (*r* = .978) and semantic neighborhood (*r* = -.768), such that words with a greater phonological length have more letters and fewer semantic neighbors. There was a significant negative correlation between orthographic length and semantic neighborhood (*r* = -.808), meaning that if a word has more letters in it, the word has fewer semantic neighbors.

Table 8 reports Pearson's correlations between psycholinguistic properties for words produced on category (animal) fluency tasks for controls participants. There were significant correlations between age of acquisition and frequency (*r* = -.892), familiarity (*r* = -.655), valence (*r* = -.582), phonological neighborhood (*r* = -.602), phonological length (*r* = .701), orthographic length (*r* = .709), and semantic neighborhood (*r* = -.810). This means that if a word is acquired earlier in life, it is more frequent, more familiar, has a more positive word-emotion association, has more phonological neighbors, has a shorter phonological length, fewer letters, and more semantic neighbors. Frequency had significant correlations to familiarity (*r* = .665), valence (*r* = .532), phonological neighborhood (*r* = .604), phonological length (*r* = -.747), orthographic length (*r* = -.760), and semantic neighborhood (*r* = .924). Words that are more frequent are more familiar, have a more positive word-emotion association, have more phonological neighbors, are shorter in phonological length, have fewer letters and more semantic neighbors. There were significant correlations between familiarity and arousal (*r* =-.421), valence (*r* = .609), phonological neighborhood (*r* = .493), phonological length (*r* = -.547), orthographic length (*r* = -

.553), and semantic neighborhood (r = .599). These results show that more familiar words are less arousing, have a more positive word-emotion association, have more phonological neighbors, are shorter in phonological length, have fewer letters, and have more semantic neighbors. Arousal had significant correlations to valence (r = -.538), phonological neighborhood (r = -.550), phonological length (r =.580), and orthographic length (r = .582). Words that are more arousing have a more negative word-emotion association, less phonological neighbors, are longer in phonological length, and have more letters. Valence had significant correlations to phonological length (r = -.444), orthographic length (r = -.468), and semantic neighborhood (r = .511). These results show that words with a more positive word-emotion association have a shorter phonological length, fewer letters, and more semantic neighbors. There were significant correlations between phonological neighborhood and phonological length (r = -.806), orthographic length (r = -.825), and semantic neighborhood (r = .627). This means that if a word has more phonological neighbors, it is shorter in phonological length, has fewer letters, and has more semantic neighbors. Phonological length had significant correlations to orthographic length (r = .980) and semantic neighborhood (r = -.788), such that words with longer phonological length have more letters and fewer semantic neighbors. Orthographic length had a significant negative correlation to semantic neighborhood (r = -.798), which represents that words with more letters have fewer semantic neighbors.

Table 5. Pearson's correlations between psycholinguistic properties in letter (F-A-S) fluency for stroke participants.

Total Words	**AoA**	**FREQ**	**FAM**	**IMAG**	**AROU**	**VAL**	**PND**	**WL**	**SND**	**N_Let**	
1	-.034	.041	-.063	-.019	.050	.175	-.123	-.051	.079	.007	**Total Words**
	1	**-.599***	**-.673***	**-.794****	.397	-.033	**-.640***	**.903****	-.086	**.898****	**AoA**
		1	.116	.101	.392	-.122	**.740****	**-.744****	.226	**-.783****	**FREQ**
			1	**.813****	**-.621***	.027	.217	-.530	-.014	-.507	**FAM**
				1	**-.710****	.211	.211	-.573	.166	-.550	**IMAG**
					1	-.111	.249	.142	-.095	.075	**AROU**
						1	-.495	.274	.481	.238	**VAL**
							1	**-.814****	-.278	**-.856****	**PND**
								1	.064	**.984****	**WL**
									1	.062	**SND**
										1	**N_Let**

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
South Carolina Metabase (SCOPE). AoA = age of acquisition. FREQ = frequency. CONC = concreteness. FAM = familiarity. IMAG = imageability. AROU = arousal. VAL = valence. PND = phonological neighborhood. WL = phonological length. SND = semantic neighborhood. N_Let = orthographic length. Total words are the number or words produced from verbal fluency. Age of acquisition is the age at which a word is acquired. Frequency follows the logarithmic functions of base 10, representing how common words are in our daily lives. Concreteness is the level in which a concept is experienced through the senses, a higher degree means it is more concrete. Familiarity means that a higher value represents a more subjectively familiar word. Imageability is the effort applied to produce a mental image of a concept with a high value signifying more imageable. Arousal indicates a high value means more arousing using the word-emotion association. Valence indicates a high value is more positive and a low value is more negative using word-emotion association. Phonological neighborhood represents how many words can be generated by varying only one phoneme while keeping the identity of the word. Phonological length is the number of phonemes in a word. Semantic neighborhood is the number of semantic neighbors within a distance in co-occurrence space. Orthographic length is the number of letters in a word.

Table 6. Pearson's correlations between psycholinguistic properties in letter (F-A-S) fluency for control participants.

Total Words	AoA	FREQ	FAM	IMAG	AROU	VAL	PND	WL	SND	N_Let	
1	.105	-.092	-.048	-.22	.278	-.251	.03	-.023	.065	-.09	**Total Words**
	1	-.864**	-.286	-.093	.295	-.033	-.640**	.720**	-.674**	.717**	**AoA**
		1	.329	-.164	-.166	.292	.625**	-.683**	.820**	-.659**	**FREQ**
			1	.008	-.286	.365	-.026	.034	.27	.017	**FAM**
				1	-.493*	-.018	.149	-.046	-.241	-.015	**IMAG**
					1	-.407*	-.368	.273	-.213	.203	**AROU**
						1	.043	.081	.425*	0.1	**VAL**
							1	-.826**	.441*	-.817**	**PND**
								1	-.462*	.976**	**WL**
									1	-.443*	**SND**
										1	**N_Let**

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
South Carolina Metabase (SCOPE). AoA = age of acquisition. FREQ = frequency. CONC = concreteness. FAM = familiarity. IMAG = imageability. AROU = arousal. VAL = valence. PND = phonological neighborhood. WL = phonological length. SND = semantic neighborhood. N_Let = orthographic length. Total words are the number or words produced from verbal fluency. Age of acquisition is the age at which a word is acquired. Frequency follows the logarithmic functions of base 10, representing how common words are in our daily lives. Concreteness is the level in which a concept is experienced through the senses, a higher degree means it is more concrete. Familiarity means that a higher value represents a more subjectively familiar word. Imageability is the effort applied to produce a mental image of a concept with a high value signifying more imageable. Arousal indicates a high value means more arousing using the word-emotion association. Valence indicates a high value is more positive and a low value is more negative using word-emotion association. Phonological neighborhood represents how many words can be generated by varying only one phoneme while keeping the identity of the word. Phonological length is the number of phonemes in a word. Semantic neighborhood is the number of semantic neighbors within a distance in co-occurrence space. Orthographic length is the number of letters in a word.

Table 7. Pearson's correlations between psycholinguistic properties in category (animal) fluency for stroke participants.

Total Words	**AoA**	**FREQ**	**FAM**	**AROU**	**VAL**	**PND**	**WL**	**N_Let**	**SND**	
1	-.219	.107	-.514	.160	-.103	-.234	.105	-.188	-.392	**Total Words**
	1	**-.922****	**-.875****	.272	**-.654***	**-.769****	**.832****	**.822****	**-.913****	**AoA**
		1	**.898****	-.208	.519	**.922****	**-.889****	**-.902****	**.971****	**FREQ**
			1	-.174	.240	**.737****	-.540	**-.611***	**.864****	**FAM**
				1	-.400	-.002	.165	.063	-.113	**AROU**
					1	-.019	-.514	-.542	.228	**VAL**
						1	**-.908****	**-.908****	**.888****	**PND**
							1	**.978****	**-.768****	**WL**
								1	**-.808****	**N_Let**
									1	**SND**

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
South Carolina Metabase (SCOPE). AoA = age of acquisition. FREQ = frequency. FAM = familiarity. AROU = arousal. VAL = valence. PND = phonological neighborhood. WL = phonological length. N_Let = orthographic length. SND = semantic neighborhood. Total words are the number or words produced from verbal fluency. Age of acquisition is the age at which a word is acquired. Frequency follows the logarithmic function of base 10, representing how common words are in our daily lives. Familiarity means that a higher value represents a more subjectively familiar word. Arousal indicates a high value means more arousing using the word-emotion association. Valence indicates a high value is more positive and a low value is more negative using word-emotion association. Phonological neighborhood represents how many words can be generated by varying only one phoneme while keeping the identity of the word. Phonological length is the number of phonemes in a word. Orthographic length is the number of letters in a word. Semantic neighborhood is the number of semantic neighbors within a distance in co-occurrence space.

Table 8. Pearson's correlations between psycholinguistic properties in category (animal) fluency for control participants.

Total Words	AoA	FREQ	FAM	AROU	VAL	PND	WL	N_Let	SND	
1	-.079	.104	.047	-.301	.075	.303	-.316	-.367	.137	**Total Words**
	1	**-.892****	**-.655****	.382	**-.582****	**-.602****	**.701****	**.709****	**-.810****	**AoA**
		1	**.665****	-.288	**.532****	**.604****	**-.747****	**-.760****	**.924****	**FREQ**
			1	**-.421***	**.609****	**.493***	**-.547****	**-.553****	**.599****	**FAM**
				1	**-.538****	**-.550****	**.580****	**.582****	-.302	**AROU**
					1	.257	**-.444***	**-.468***	**.511****	**VAL**
						1	**-.806****	**-.825****	**.627****	**PND**
							1	**.980****	**-.788****	**WL**
								1	**-.798****	**N_Let**
									1	**SND**

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
South Carolina Metabase (SCOPE). AoA = age of acquisition. FREQ = frequency. FAM = familiarity. AROU = arousal. VAL = valence. PND = phonological neighborhood. WL = phonological length. N_Let = orthographic length. SND = semantic neighborhood. Total words are the number or words produced from verbal fluency. Age of acquisition is the age at which a word is acquired. Frequency follows the logarithmic function of base 10, representing how common words are in our daily lives. Familiarity means that a higher value represents a more subjectively familiar word. Arousal indicates a high value means more arousing using the word-emotion association. Valence indicates a high value is more positive and a low value is more negative using word-emotion association. Phonological neighborhood represents how many words can be generated by varying only one phoneme while keeping the identity of the word. Phonological length is the number of phonemes in a word. Orthographic length is the number of letters in a word. Semantic neighborhood is the number of semantic neighbors within a distance in co-occurrence space.

Regression Analysis of Language and Cognitive Measures on Fluency Performance

Language and cognitive measures were used to predict fluency scores on verbal fluency tasks. These measures reflected semantic processing, phonological skills, and speech production composites and were entered as predictors in the regression models. The composites comprised of the average percent scores of the assessments related to each measure. Semantic processing consisted of the Boston Naming Test, Peabody Picture Vocabulary Test, Camel and Cactus Test, written word-picture match (PALPA 48), and auditory synonym judgment (PALPA 49) tests. The composite for phonological skills comprised of the phoneme deletion (words), phoneme deletion (nonwords), phoneme blending (words), phoneme blending (nonwords), phoneme replacement (words), and phoneme replacement (nonwords) assessments. Speech production incorporated the repeat nonwords (CNRT), repeat words (PALPA 11), and Arizona Phonological Battery (APB) repetition tests. **Table 9** reports the results of the regression model investigating the contribution of semantic, phonology, and speech production on the total words produced on letter (F-A-S) fluency tasks. The regression model was significant (R^2 = .72; $F(3,8) = 6.71$; p = .014), with only <u>phonological skills</u> (β = .95; $t(8) = 4.43$; p = .002) significantly predicting total words produced on letter fluency tasks. Indicating that a higher score on phonology tests was related to better performance, and these tests were predictors for fluency scores on letter (F-A-S) fluency tasks. For category fluency the regression models were not significant.

Table 9. Regression coefficients for predicting total words produced in letter (F-A-S) fluency using language and cognitive measures.

	Unstandardized Coefficients	**Standardized Coefficients**		
Predictor	**B**	**β**	***t***	***p-value***
(Constant)	4.583		0.538	.605
Semantics Composite	-.009	-.018	-.093	.928
Phonology Composite	.132	.951	4.432	**.002***
Speech Production Composite	-.061	-.331	-1.535	.163

R^2 = .72 (n = 38, p = .014). $F(3,8)$ = 6.706. Bold values are significant.
Semantics Composite: Boston Naming Test, Peabody Picture Vocabulary Test, Camel and Cactus Test, Written word-picture match (PALPA 48), Auditory synonym judgment (PALPA 49); Phonology Composite: Phoneme deletion (words), Phoneme deletion (nonwords), Phoneme blending (words), Phoneme blending (nonwords), Phoneme replacement (words), Phoneme replacement (nonwords); Speech Production Composite: Repeat nonwords (CNRT), Repeat words (PALPA 11), Arizona Phonological Battery (APB) repetition.

DISCUSSION

In the present study, we examined the differences in the psycholinguistic properties of words generated on two verbal fluency tasks in individuals with post-stroke aphasia and neurotypical controls. The goal was to identify which word properties showed significant differences in word generation on the fluency tasks. The two types of tasks that the participants completed were letter (F-A-S) fluency and category (animal) fluency. We also analyzed language and cognitive measures as predictors for the total words produced on these tasks.

Stroke participants had impaired performance on both fluency tasks. This finding is in line with previous reports on verbal fluency tasks in post-stroke aphasia (Bose et al., 2022;

Roberts & Dorze, 1994). In line with our results, a previous study that examined confrontation naming in individuals with post-stroke aphasia showed similar results (Boucher et al., 2020). This coincides with the notion that those with post-stroke aphasia perform worse on word finding tasks compared to healthy controls. Our findings also align with those of other studies that compared verbal fluency performance in other clinical populations to that of healthy older adults (Henry & Crawford, 2004; Paek & Murray, 2021; Van den Berg et al., 2022). Results from those studies showed that individuals with probable Alzheimer's disease (pAD), Parkinson's disease, and primary progressive aphasia demonstrated impaired cognitive-linguistic skills and produced fewer correct words during the verbal fluency tasks (Henry & Crawford, 2004; Paek & Murray, 2021; Van den Berg et al., 2022).

The psycholinguistic properties that appeared to have the most significant differences on number of words produced on letter (F-A-S) fluency tasks between individuals with aphasia and controls were *age of acquisition, frequency, phonological neighborhood, and semantic neighborhood*, while there were no word properties showing significant differences in performance on category (animal) fluency tasks. Age of acquisition was identified as a significant variable regarding accuracy in confrontation naming and the quality of words produced during verbal fluency tasks for individuals with pAD (Paek & Murray, 2021). Interestingly, this property has been more closely related to lexical processing and phonological code retrieval than semantic processing (Kittredge et al., 2008; Rofes et al., 2020). Frequency was also significantly different between individuals with aphasia and controls for letter fluency performance. Similar studies have reported that individuals with a certain type of primary progressive aphasia, semantic variant primary progressive aphasia (svPPA), and with Alzeihmer's disease (AD) produce fewer and more frequent words in verbal fluency tasks compared to those who are neurotypical (Rofes et al., 2020). This concurs with our findings that individuals with aphasia produce words that are more frequent on letter fluency tasks. Relevant to this, frequency is also associated with phonological code retrieval, which explains why it showed significant differences between the fluency scores of the two groups (Wilson et al., 2009). Previous research has also demonstrated that phonological neighborhood is strongly related to phonological code retrieval and has been found to influence word production (Peramunage et al., 2011). Putting this information together, it is possible that age of acquisition, frequency, and phonological neighborhood were significantly different psycholinguistic properties for letter fluency performance due to their relation to phonological code retrieval, especially in the light of the profiles of our sample.

Another compelling finding of our study was the effect of semantic neighborhood, such that individuals with post-stroke aphasia produced words that were more semantically dense than control participants. Research on semantic neighborhood shows that it relates to the semantic system (Buchanan et al., 2001). While this may seem counterintuitive, the letter fluency task does require semantic processing, which may explain our findings. In fact, this task has been shown to require the interplay between both systems, with more weight being attributed to phonology but semantics emerging as an important system nonetheless (Riello et al., 2021).

Supporting our interpretation, **Table 5** shows that age of acquisition, frequency, and phonological neighborhood were significantly correlated to one another, while semantic neighborhood showed no significant relationship to these properties for words produced on letter fluency tasks for stroke participants. This strengthens the assumption that the former three properties are associated with an underlying process (i.e., phonological code retrieval) and semantic neighborhood is associated with another underlying process (i.e., conceptual preparation), and that both processes may have differential contribution to the word properties produced in the task. Additionally, this phenomenon was reflected in the other properties, such that word properties that have demonstrated to reflect lexical-phonological skills (i.e., word length, orthographic and phonological similarity, and frequency) were correlated with one another. Similarly, word properties that have been shown to relate to semantic processes (i.e. familiarity and imageability) were correlated to each other. Further research would need to be conducted to understand why semantic neighborhood showed significant differences of letter fluency performance between individuals with aphasia and controls in this study when it has been found to be associated with semantic processes in previous research.

Regarding the language and cognitive systems that affect letter fluency performance, our regression model showed that only the phonological system predicted the total number of words generated in letter fluency, such that better phonological skills contributed to a greater production of words. This is consistent with previous reports that have shown a strong relationship between letter fluency and phonological skills (Baldo et al., 2006; Biesbroek et al., 2016; Shao et al., 2014; Vonk et al., 2019). For category fluency, neither semantic processing, phonological skills, nor speech production was significant. This could be because our post-stroke aphasia cohort was not considerably impaired in semantics. This means that the individuals with aphasia who participated in our study could have only minimal deficit/impairments to their semantic processes, so the composites associated with semantics would not show to be predictive regarding category fluency performance.

Individuals with post-stroke aphasia included in our study had significant differences with age of acquisition, frequency, phonological neighborhood, and semantic neighborhood compared to controls. They also demonstrated impaired phonological code retrieval and phonology was a significant predictor of number of words generated for letter fluency tasks. Our results indicate that performance on letter fluency is related to phonological deficits in individuals with post-stroke aphasia and that may be due to difficulty accessing phonological code retrieval or can be caused by damage to the phonological code retrieval itself (Rofes et al., 2020). Our findings have clinical implications, such that they can help clinicians further understand the cognitive and linguistic status of individuals with aphasia and can also be used to further study other potential predictors for verbal fluency performance.

Limitations of the Study

The limitation of the study was a small sample size that may have reduced power to detect small effects.

CONCLUSION

In this study, we have examined factors of verbal fluency performance in individuals with post-stroke aphasia. We analyzed psycholinguistic properties of words produced and looked at cognitive and language measures to determine differences in language processing between individuals with aphasia and controls. Our findings showed that words were significantly different in their age of acquisition, frequency, phonological neighborhood, and semantic neighborhood between individuals with aphasia and controls. Our findings also demonstrated that letter (F-A-S) fluency relies more on phonology, than semantics. This information can be beneficial in understanding factors that influence word generation in post-stroke aphasia. These data can assist clinicians in the development of treatments for those who are affected by aphasia. The results can be of potential benefit for research on the effect of psycholinguistic properties on verbal fluency performance in other clinical populations that share similar features to post-stroke aphasia.

REFERENCES

Adlam, Anna-Lynne R., et al. (2010). “The Cambridge Semantic Memory Test Battery: Detection of Semantic Deficits in Semantic Dementia and Alzheimer's Disease.” *Neurocase,* vol. 16, no. 3, pp. 193–207., https://doi.org/10.1080/13554790903405693.

Alyahya, Reem S.W., et al. (2020). “Mapping Psycholinguistic Features to the Neuropsychological and Lesion Profiles in Aphasia.” *Cortex,* vol. 124, pp. 260–273., https://doi.org/10.1016/j.cortex.2019.12.002.

Baldo, Juliana V., et al. (2006). “Role of Frontal versus Temporal Cortex in Verbal Fluency as Revealed by Voxel-Based Lesion Symptom Mapping: Journal of the International Neuropsychological Society.” *Cambridge Core,* Cambridge University Press, https://www.cambridge.org/core/journals/journal-of-the-international-neuropsychological-society/article/abs/role-of-frontal-versus-temporal-cortex-in-verbal-fluency-as-revealed-by-voxelbased-lesion-symptom-mapping/86562C8AF93BFCC9626A481CC90ECBCE.

Balota, David A., et al. (2007) “The English Lexicon Project.” *Behavior Research Methods,* vol. 39, no. 3, pp. 445–459., https://doi.org/10.3758/bf03193014.

Beeson, et al. (2010). “A Treatment Sequence for Phonological Alexia/Agraphia.” *Journal of Speech, Language, and Hearing Research: JSLHR,* U.S. National Library of Medicine, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3522177/.

Biesbroek, J. Matthijs, et al. (2016). “Shared and Distinct Anatomical Correlates of Semantic and Phonemic Fluency Revealed by Lesion-Symptom Mapping in Patients with Ischemic Stroke.” *Brain Structure and Function,* vol. 221, no. 4, pp. 2123–2134., https://doi.org/10.1007/s00429-015-1033-8.

Boucher, Johémie, et al. (2020). "Word-Finding in Confrontation Naming and Picture Descriptions Produced by Individuals with Early Post-Stroke Aphasia." *The Clinical Neuropsychologist*, vol. 36, no. 6, pp. 1422–1437., https://doi.org/10.1080/13854046.2020.1817563.

Bose, Arpita, et al. (2022). "Verbal Fluency Difficulties in Aphasia: A Combination of Lexical and Executive Control Deficits." *International Journal of Language & Communication Disorders*, vol. 57, no. 3, pp. 593–614., https://doi.org/10.1111/1460-6984.12710.

Buchanan, Lori, et al. (2001). "Characterizing Semantic Space: Neighborhood Effects in Word Recognition - Psychonomic Bulletin & Review." *SpringerLink*, Springer-Verlag, https://link.springer.com/article/10.3758/BF03196189

Brysbaert, Marc, and Boris New. (2009) "Moving beyond Kučera and Francis: A Critical Evaluation of Current Word Frequency Norms and the Introduction of a New and Improved Word Frequency Measure for American English." *Behavior Research Methods*, vol. 41, no. 4, pp. 977–990., https://doi.org/10.3758/brm.41.4.977.

Brysbaert, Marc, and Andrew W. Ellis. (2016). "Aphasia and Age of Acquisition: Are Early-Learned Words More Resilient?" *Aphasiology*, vol. 30, no. 11, pp. 1240–1263., https://doi.org/10.1080/02687038.2015.1106439.

Cho-Reyes, Soojin, and Cynthia K. Thompson. (2012). "Verb and Sentence Production and Comprehension in Aphasia: Northwestern Assessment of Verbs and Sentences (NAVS)." *Aphasiology*, vol. 26, no. 10, pp. 1250–1277., https://doi.org/10.1080/02687038.2012.693584.

Danguecan, Ashley N., and Lori Buchanan. (2016). "Semantic Neighborhood Effects for

Abstract versus Concrete Words." *Frontiers in Psychology*, vol. 7, https://doi.org/10.3389/fpsyg.2016.01034.

Delis, Dean C., et al. (2001). "Delis-Kaplan Executive Function System." *PsycTESTS Dataset*, https://doi.org/10.1037/t15082-000.

Dunn, L. M., & Dunn, D. M. (2007). *PPVT-4: Peabody picture vocabulary test*. Pearson Assessments.

Ehara, Yo. (2017). "Language-Independent Prediction of Psycholinguistic Properties of Words." *ACL Anthology*, https://aclanthology.org/I17-2056/.

Fridriksson, Julius, et al. (2005). "Spaced Retrieval Treatment of Anomia." *Aphasiology*, vol. 19, no. 2, pp. 99–109., https://doi.org/10.1080/02687030444000660.

Fridriksson, Julius, et al. (2018). "Anatomy of Aphasia Revisited." *Brain*, vol. 141, no. 3, pp. 848–862., https://doi.org/10.1093/brain/awx363.

Fyndanis, Valantis, et al. (2017). "Cross-Linguistic Adaptations of *the Comprehensive Aphasia Test*: Challenges and Solutions." *Clinical Linguistics & Phonetics*, vol. 31, no. 7-9, pp. 697–710., https://doi.org/10.1080/02699206.2017.1310299.

Gao, C., et al. (2022). SCOPE: The South Carolina psycholinguistic metabase. *Behav Res*. https://doi.org/10.3758/s13428-022-01934-0.

Gathercole, Susan E., et al. (1994). "The Children's Test of Nonword Repetition: A Test of Phonological Working Memory." *Memory*, vol. 2, no. 2, pp. 103–127., https://doi.org/10.1080/09658219408258940.

Henry, Julie D., and John R. Crawford. (2004)."Verbal Fluency Deficits in Parkinson's Disease: A Meta-Analysis." *Journal of the International Neuropsychological Society*, vol. 10, no. 4, 2004, pp. 608–622., https://doi.org/10.1017/s1355617704104141.

Kaplan, E., et al. (1983). *The Boston Naming Test*. Philadelphia, PA: Lea & Febiger.

Kay, J., et al. (1992). PALPA: Psycholinguistic Assessments of Language Processing in Aphasia (Lawrence Erlbaum Associates, Hove).

Kertesz A. (2007). Western Aphasia Battery–Revised. San Antonio, TX: The Psychological Corporation.

Kittredge, Audrey K., et al. (2008). "Where Is the Effect of Frequency in Word Production? Insights from Aphasic Picture-Naming Errors." *Cognitive Neuropsychology*, vol. 25, no. 4, pp. 463–492., https://doi.org/10.1080/02643290701674851.

Kuperman, Victor, et al. (2012). "Age-of-Acquisition Ratings for 30,000 English Words." *Behavior Research Methods*, vol. 44, no. 4, pp. 978–990., https://doi.org/10.3758/s13428-012-0210-4.

Le, Huykien, and Mickey Y. Lui. (2022). *Aphasia - Statpearls - NCBI Bookshelf*, https://www.ncbi.nlm.nih.gov/books/NBK559315/.

Loveridge, Corinne Jones. (2020). "Effects of Positive and Negative Emotional Valence on Response Time During a Confrontational Naming Task: Findings from People with Aphasia and Young Adults". Theses and Dissertations. 9088.

Mohammad, S. and P. Turney. (2010). Emotions evoked by common words and phrases: Using mechanical turk to create an emotion lexicon. Proceedings of the NAACL HLT 2010 workshop on computational approaches to analysis and generation of emotion in text. Mohammad, S.M. and P.D. Turney. (2013). "Crowdsourcing a word-emotion association lexicon." *Computational Intelligence*, vol. 29, no. 3, pp. 436–465., https://doi.org/10.1111/j.1467-8640.2012.00460.x.

Na, Yoonhye, et al. (2022). “Language Systems from Lesion-Symptom Mapping in Aphasia: A Meta-Analysis of Voxel-Based Lesion Mapping Studies.” *NeuroImage: Clinical*, vol. 35, p. 103038., https://doi.org/10.1016/j.nicl.2022.103038.

Nasreddine, Ziad S., et al. (2005). “The Montreal Cognitive Assessment, MOCA: A Brief Screening Tool for Mild Cognitive Impairment.” *Journal of the American Geriatrics Society*, vol. 53, no. 4, pp. 695–699., https://doi.org/10.1111/j.1532-5415.2005.53221.x.

Oldfield, R. C. (1971). “Edinburgh Handedness Inventory.” *PsycTESTS Dataset*, https://doi.org/10.1037/t23111-000.

Paek, Eun Jin, and Laura L. Murray. (2021). “Quantitative and Qualitative Analysis of Verb Fluency Performance in Individuals with Probable Alzheimer's Disease and Healthy Older Adults.” *American Journal of Speech-Language Pathology*, vol. 30, no. 1S, pp. 481–490., https://doi.org/10.1044/2019_ajslp-19-00052.

Peramunage, Dasun, et al. (2011). “Phonological Neighborhood Effects in Spoken Word Production: An Fmri Study.” *Journal of Cognitive Neuroscience*, vol. 23, no. 3, pp. 593–603., https://doi.org/10.1162/jocn.2010.21489.

Riello, Marianna, et al. (2021). “Neural Correlates of Letter and Semantic Fluency in Primary Progressive Aphasia.” *Brain Sciences*, vol. 12, no. 1, p. 1., https://doi.org/10.3390/brainsci12010001.

Roberts, Patricia, and Guylaine Le Dorze. (1994). “Semantic Verbal Fluency in Aphasia: A Quantitative and Qualitative Study in Test-Retest Conditions.” *Aphasiology*, vol. 8, no. 6, pp. 569–582., https://doi.org/10.1080/02687039408248682.

Rofes, Adrià, et al. (2019). “The Role of Word Properties in Performance on Fluency Tasks in

People with Primary Progressive Aphasia." *Journal of Alzheimer's Disease : JAD*, U.S. National Library of Medicine, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6548439/.

Rofes, Adrià, et al. (2020). "What Drives Task Performance during Animal Fluency in People with Alzheimer's Disease?" *Frontiers in Psychology*, vol. 11, https://doi.org/10.3389/fpsyg.2020.01485.

Sathian, K., and Bruce Crosson. (2015). "Structure-Function Correlations in Stroke." *Neuron*, vol. 85, no. 5, pp. 887–889., https://doi.org/10.1016/j.neuron.2015.02.031.

Scott, Graham G., et al. (2019). "The Glasgow Norms: Ratings of 5,500 Words on Nine Scales." *Behavior Research Methods*, vol. 51, no. 3, pp. 1258–1270., https://doi.org/10.3758/s13428-018-1099-3.

Shao, Zeshu, et al. (2014). "What Do Verbal Fluency Tasks Measure? Predictors of Verbal Fluency Performance in Older Adults." *Frontiers in Psychology*, vol. 5, https://doi.org/10.3389/fpsyg.2014.00772.

Shaoul, Cyrus, and Chris Westbury. (2006). "Word Frequency Effects in High-Dimensional Co-Occurrence Models: A New Approach." *Behavior Research Methods*, vol. 38, no. 2, pp. 190–195., https://doi.org/10.3758/bf03192768.

Sheppard, Shannon M., and Rajani Sebastian. (2022). "Diagnosing and Managing Post-Stroke Aphasia." *Expert Review of Neurotherapeutics*, vol. 21, no. 2, pp. 221–234., https://doi.org/10.1080/14737175.2020.1855976.

Thompson, C. K. (2011). Northwestern Assessment of Verbs and Sentences. Evanston, IL.

Tóth, Odett, et al. (2022). "Intact Fluency in Autism? A Comprehensive Approach of Verbal

Fluency Task Including Word Imageability and Concreteness.” *Autism Research*, vol. 15, no. 4, pp. 677–686., https://doi.org/10.1002/aur.2672.

Van den Berg, E., et al. (2022). “Differential Linguistic Features of Verbal Fluency in Behavioral Variant Frontotemporal Dementia and Primary Progressive Aphasia.” *Applied Neuropsychology: Adult*, pp. 1–9., https://doi.org/10.1080/23279095.2022.2060748.

Vonk, Jet M, et al. (2019). “Letter and Category Fluency Performance Correlates with Distinct Patterns of Cortical Thickness in Older Adults.” *Cerebral Cortex*, vol. 29, no. 6, pp. 2694–2700., https://doi.org/10.1093/cercor/bhy138.

Warrington, E. K. (1984). Recognition Memory Test: Manual. NFER-Nelson.

Wechsler, D. (2008). WAIS-IV administration and scoring manual. San Antonio, TX: The Psychological Corporation.

Wilson, Stephen M., et al. (2009). “Neural Correlates of Word Production Stages Delineated by Parametric Modulation of Psycholinguistic Variables.” *Human Brain Mapping*, vol. 30, no. 11, pp. 3596–3608., https://doi.org/10.1002/hbm.20782.