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Research Report

Comparison of animal, action and phonemic fluency in aphasia

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Abstract

Background: The ability to generate words that follow certain constraints, or verbal fluency, is a sensitive indicator of neurocognitive impairment, and is impacted by a variety of variables.
Aims: To investigate the effect of post-stroke aphasia, elicitation category and linguistic variables on verbal fluency performance.
Methods & Procedures: Twenty-eight persons with aphasia (PWA) with a single left-hemisphere lesion and 40 age-matched neurotypical community-dwelling adults were administered three verbal fluency tasks: two semantic (animals and actions) and one phonemic (the letters F, A and S). Data analysis included comparison of total scores, clusters and perseverations. Individual responses were coded for frequency of occurrence, age of acquisition and syllable length to investigate qualitative differences in word generation.
Outcomes & Results: PWA performed worse than neurotypical participants across all verbal fluency tasks, and animal fluency scores were farthest from neurotypical performance. PWAs' animal and action fluency were correlated with other language measures, while phonemic fluency was uncorrelated with language measures. While some PWAs showed dissociations between verbal fluency tasks, the dissociations did not pattern along with aphasia fluency. PWAs produced fewer clusters and responses with higher word frequency across all three verbal fluency tasks. Responses had earlier age of acquisition and shorter word length for animal and phonemic fluency, but not action fluency.
Conclusions & Implications: Verbal fluency, particularly animal fluency, is sensitive to even mild aphasia. PWA produced lexically simpler responses than their neurotypical peers. This study identifies the relevance of qualitative analysis of verbal fluency responses.

Keywords: action, age-of-acquisition, clustering, phonemic, semantic, verbal fluency, word frequency.

What this paper adds

What is already known on the subject

Word retrieval is impaired in aphasia. Verbal fluency has been primarily studied with noun (animal) fluency. PWAs produce fewer responses with smaller clusters compared with neurologically healthy controls.

What this paper adds to existing knowledge

This study provides data and relative comparisons on three different verbal fluency tasks in the same group of PWAs. To our knowledge, this is the first such study, and the first report of action fluency, in aphasia. Individual responses are analyzed for psycholinguistic properties, showing that PWAs produce lexically simpler responses (higher frequency, earlier age of acquisition, shorter word length). This psycholinguistic analysis is novel for verbal fluency in general, and aphasia in particular. The study also revealed that animal and action fluency are correlated with standardized language test performance, while phonemic fluency is not. Thus, consistent with findings in other neurological impairments, the neural basis of phonemic fluency is partially independent of language networks.

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What are the potential or actual clinical implications of this work?
The study provides psychometric data, including *z*-scores, for each verbal fluency task. The findings reveal that verbal fluency is sensitive to even mild aphasia and animal fluency has the greatest sensitivity. Action fluency was least impaired of the verbal fluency tasks, despite the well-documented verb retrieval difficulties in aphasia. Thus, the study provides data for clinical interpretation of verbal fluency performance. The finding that PWA produce fewer clusters implies weaker semantic organization, which attest the importance of strengthening semantic networks in clinical intervention of PWA.

Introduction

Evaluation of word-retrieval performance is ubiquitous in neurologically based cognitive and communicative disorders. Word retrieval is commonly assessed by eliciting narratives, picture naming or verbal fluency. Verbal fluency refers to free generation of words that meet a preset criterion (e.g., animal names) in a fixed amount of time, such as 1 min. Verbal fluency measures have played an important role in the assessment of neurogenic populations for several reasons. Verbal fluency tasks are quick to administer, have good test quality, do not require any test materials and do not rely on culturally specific stimuli. Successful verbal fluency performance relies on the integrity of semantic networks for word retrieval and cognitive control for effective search strategies. Hence, these measures are sensitive to a wide range of neuropsychological aberrations including subtle communicative and cognitive changes in conditions such as mild traumatic brain injury (TBI) and mild cognitive impairment (reviewed by Thiele *et al.* 2016).

Norms for different verbal fluency tasks and performance profiles for various neurocognitive conditions have been published (e.g., Davis *et al.* 2010, Henry and Crawford 2004, Tombaugh *et al.* 1999, Troyer *et al.* 2011, Woods *et al.* 2005). Despite its frequent use in clinical settings with persons with aphasia (PWA), relatively little research has been devoted to verbal fluency performance in this clinical population. For example, it is unclear how the specific verbal fluency task, severity and pattern of language impairment impact verbal fluency performance in PWA. Whether PWA utilize similar retrieval strategies and produce qualitatively similar responses compared with neurotypical adults also needs to be examined. Hence, this study investigated the effect of verbal fluency elicitation task and linguistic variables in PWA. This not only will provide reference scores for clinical use but also will further our understanding of the integrity of lexical–semantic networks and executive functioning in aphasia. In the following, we briefly review the different verbal fluency tasks, their neurocognitive implications and variables that are known to impact performance.

A classic and widely used verbal fluency task is the Controlled Oral Word Association Test (COWAT; Benton 1968), which involves generation of words (excluding proper names) that begin with the letters F, A and S for 1 min each. This test has been alternately called FAS, letter fluency and phonemic fluency, and is included in a variety of neurocognitive test batteries (e.g., Dubois *et al.* 2000). It also has been elicited with the letters CFL and PRW, which are better matched for difficulty based on the number of English words that begin with these letters (Benton *et al.* 1994). In this paper, we will refer to this task as phonemic fluency. Phonemic fluency performance differentiates individuals with focal frontal lesions from neurologically healthy individuals (Chapados and Petrides 2013, Jurado *et al.* 2000). It is not particularly sensitive to conditions such as depression, Huntington's disease and Alzheimer's disease (Henry and Crawford 2005, Henry *et al.* 2004, 2005), and its ability to differentiate between degenerative conditions is mixed (conflicting results of Marczinski and Kertesz 2006 versus Marra *et al.* 2007). Research on phonemic fluency in PWA is scant. There are two case studies with two participants each (Baldo *et al.* 2010, Coelho *et al.* 1987). Baldo *et al.* (2010) reported a double dissociation, suggesting a role of left frontal and temporal regions for phonemic and semantic fluency respectively.

Another verbal fluency task is semantic fluency, also called category fluency. This involves generation of words in a specific semantic category, such as animals (most common), foods, clothing and tools. Semantic fluency is more impaired in conditions implicating the temporal lobe (e.g., Alzheimer's disease, semantic dementia) compared with frontal lobe atrophy (e.g., PnFA) (Baldo *et al.* 2006, Henry *et al.* 2004, Henry and Crawford 2004, Libon *et al.* 2009). Although animal fluency is part of the two most commonly used standardized aphasia test batteries in English (Goodglass *et al.* 2001, Kertesz 2006), there are only a handful of studies on animal (or other semantic) fluency in aphasia. These have included comparisons with neurotypical adults (Adams *et al.* 1989, Bose *et al.* 2017, Roberts and LeDorze 1994), non-aphasic stroke survivors (Kim *et al.* 2011), or case studies (Baldo *et al.* 2010, Coelho *et al.* 1987) across a variety of semantic categories (animals, clothing, colours, crimes, food, instruments, vegetables and tools). Overall, these studies found fewer and slower responses relative to neurotypical adults, and these differences were evident within the first 30 s of elicitation. Given semantic fluency's presumed sensitivity to temporal lobe lexical networks, we need to further understand patterns of semantic fluency across aphasia profiles.

Although semantic fluency is conventionally elicited with animal names, action fluency has emerged as another clinically useful category (Piatt *et al.* 1999). It is elicited by requesting participants to *name things that people do*, while avoiding inflectional variants of the same action (e.g., *eat* and *eating*). In neurotypical adults, action fluency is correlated with executive function measures but not with measures of episodic memory and noun retrieval (Beber and Chaves 2014, Piatt *et al.* 2004). In neuropathological populations, action fluency differentiates between Parkinson's disease with dementia (PDD) and non-demented Parkinson's disease (Piatt *et al.* 1999), between Lewy body dementia and Alzheimer's dementia (Delbeuck *et al.* 2013), as well as between PnFA/behavioural variant of frontotemporal dementia and Alzheimer's dementia (Davis *et al.* 2010). Overall, action fluency is sensitive to conditions that affect verb retrieval and frontostriatal networks. Verb naming can be significantly impaired in PWA (Mätzig *et al.* 2009), and so it is crucial to investigate PWA performance on action fluency. To summarize, the three verbal fluency tasks (phonemic, animal and action) are clinically sensitive to neuropathology. Performance on these tasks differs across clinical conditions because each task relies on at least partially unique neuroanatomical substrates and cognitive mechanisms.

Verbal fluency recruits two types of cognitive processes. One is linguistic, particularly efficient access to lexical–semantic representations. The other is executive processing, such as speeded strategic search, allocation of attentional resources, ongoing monitoring of task requirements and inhibition of previously generated responses (Troyer *et al.* 1998, Unsworth *et al.* 2011). Further, the strategic search involves two steps: identifying subcategories (e.g., farm animals) and generating examples of a subcategory, followed by switching to another subcategory after the initial subcategory exemplars have been exhausted. The relative contribution of these linguistic and executive sub-processes cannot be captured by just counting the total number of responses generated. The number and size of *clusters* (subcategories) reflects the integrity of semantic networks, the number of subcategory *switches* reflects executive strategic search processes, and the number of perseverative responses, reflects an inability to inhibit prior responses. In a meta-analysis of verbal fluency measures, Thiele *et al.* (2016) found that clustering and perseverations had larger effect sizes than other response analyses. Very little is known about these measures in PWA, except that, for animal fluency, PWA produce smaller cluster sizes, pause longer between clusters and produce fewer clusters than neurotypical adults (Bose *et al.* 2017, Kiran *et al.* 2014).

Depending on the severity of language impairment in PWA, analysis of clusters, switches and perseverations could be constrained by the small number of responses produced. Hence, it may be necessary to use other response measures. PWA may cope with their generally compromised lexical–semantic system by producing words that are more accessible. This may include words with higher frequency of occurrence, earlier age of acquisition or shorter word length. More frequent and earlier acquired words have more robust lexical semantic representations (Ellis and Morrison 1998) and thus be more resilient to the effects of brain damage (Kittredge *et al.* 2008, Nickels and Howard 1995). Additionally, the demands of phonological and articulatory encoding could be lessened by producing shorter words. To our knowledge, these psycholinguistic characteristics have not been investigated systematically for verbal fluency in neurocognitive impairments, except for word frequency in two studies (TBI: Silverberg *et al.* 2008; degenerative disorders: Marczinski and Kertesz 2006).

The present study

The first goal of this study was to report and compare the performance of PWA and their neurotypical peers on three verbal fluency tasks: animal, action and phonemic fluency. We predicted that PWA would perform worse than neurotypical adults across all three tasks, and that there would be worse performance on semantic compared with phonemic tasks, due to the significant lexical difficulties characteristic of aphasia. Our second goal was to examine differences in responses between the two groups. We analyzed clusters and perseverations, as well as word frequency, age of acquisition and word length of individual responses. We predicted that PWAs' responses would be qualitatively inferior to neurotypical adults, showing fewer clusters, higher word frequency, earlier age of acquisition and shorter word length. The third goal was to identify variables that influence verbal fluency performance in each participant group, including linguistic and response-related variables. In PWA, we predicted an effect of overall aphasia severity for all three tasks. Additionally, in PWA, we predicted that animal and action fluency would pattern with noun and verb naming scores respectively. We also hypothesized that action and phonemic fluency performance would pattern together given their reliance on overlapping left frontal regions.

Table 1. Demographic data and test scores of neurotypical and aphasic groups

	Neurotypical	Aphasia
	Mean (SD)	
Number	40	29
Age (years)	62.5 (16.1)	60.2 (14.4)
Education (years)	16.2 (2.6)	15.8 (4)
Handedness	39 right-handed	22 right-handed
Mini Mental State Examination (maximum = 30)	28.5 (2.5)	20.6 (6.5)
Raven's Colored Progressive Matrices (maximum = 36)	31.1 (4)	26.7 (5.7)
Boston Naming Test (maximum = 60)	55.8 (3.1)	29.7 (14.6)
Verb Naming Test (maximum = 30)	21 (1.2)	14.5 (6)
Western Aphasia Battery—Revised		
Information content (maximum = 10)	10 (0)	7.9 (2.8)
Spontaneous speech fluency (maximum = 10)	10 (0)	6.8 (2.8)
Naming composite score (maximum = 10)	9.8 (0.3)	7.2 (2.1)
Aphasia quotient (maximum = 100)	99.2(0.7)	74.7 (20.5)

Methods

Participants

Twenty-nine individuals with aphasia (16 female, 13 male, age range 37–87 years) and 40 neurotypical adults (30 female, 10 male, age range 23–85 years) participated. Participants were recruited in the Washington, DC, metropolitan area and from Logan, Utah. All participants were primary speakers of English, had at least a high-school education and past depression (score < 6, Geriatric Depression Scale; Sheikh and Yesaveage 1986), hearing (500, 1000 and 2000 Hz at 40 dB HL) and vision (self-completion of demographic questionnaire) screenings. None of the participants reported a prior history of neuropsychiatric disorders. Participant details are shown in table 1. Neurotypical adults were independent community-dwelling adults. The age-wise incidence of cerebrovascular accidents in the US population was used to guide recruitment of neurotypical adults in specific age groups in the age range of 18–95 years (Mozaffarian *et al.* 2015). Neurotypical adults did not differ in age ($t(65) = 0.14$, $p > .05$) and education ($t(65) = 1.07$, $p > .05$) from PWA.

All participants with aphasia had suffered a single left hemisphere cerebrovascular accident (CVA) in the middle cerebral artery region at least 6 months prior to participation. The group represented a wide range of severity (Aphasia Quotient of Western Aphasia Battery—Revised; Kertesz 2006; mean (SD) = 74.7 (20.5), range = 12.7–93.8). The subtypes included 13 anomic, nine Broca's, two transcortical motor, three conduction, and two with global aphasia.

Procedures

The research was conducted with Institutional Review Board approval at the University of Maryland and Utah State University and is compliant with the Helsinki Declaration. All testing was conducted in a quiet setting, either at the investigators' research facility or in the participant's home and was completed in a single session for neurotypical adults and over two sessions for PWA. After providing informed consent, a demographic interview was conducted. This was followed by administration of standard language and cognitive measures and the verbal fluency tasks (although all verbal fluency tasks were administered within the same session). Participants were paid US$20 per testing session for participation.

Language and cognitive background

Language testing included the Western Aphasia Battery—Revised (WAB-R; Kertesz 2006), Boston Naming Test (BNT; Goodglass *et al.* 2001), Verb Naming Test (VNT, from Northwestern Assessment of Verbs and Sentences—Revised; Cho-Reyes and Thompson 2012), and narrative language samples. The WAB-R provides an overall language proficiency score (aphasia quotient, out of 100) and domain scores for information content, fluency, auditory comprehension, repetition and naming. It also provides a aphasia subtype classification. The BNT is a 60-item picture-naming test with black-and-white line drawings of objects of increasing difficulty level. According to standard administration procedures, PWA are administered all 60 items, while testing for neurotypical adults begins at item number 30. The VNT is a 22-item picture-naming test of intransitive and transitive actions with black-and-white line drawings.

Cognitive measures were used to rule out cognitive decline in neurotypical adults. These included the Mini-Mental State Exam (MMSE; Folstein *et al.* 1975) and Raven's Colored Progressive Matrices (RCPM; Raven and Court 1998). The MMSE is a 22-item cognitive screen of orientation, registration, attention, memory, language and visuospatial function. The maximum score is 30. The RCPM is a 36-item nonverbal reasoning/executive function test assessing design completion in a multiple-choice format. Neurotypical adults scored within the normal range for both tests. Interpretation of PWAs' MMSE performance is confounded by its high reliance on verbal input and output, and therefore was not used to screen for cognitive decline (table 1).

Verbal fluency tasks

Three verbal fluency tasks were administered: two semantic (animals and actions) and one phonemic (the letters F, A and S). Elicitation of animal fluency was completed as part of the WAB-R testing (Kertesz 2006), in which participants were instructed to name as many animals as they could in 1 min. Action fluency elicitation procedures followed Piatt *et al.* (1999) and the verbatim instructions were:

> I'd like you to tell me as many different things as you can think of that people do. I don't want you to use the same word with different endings, like eat, eating, eaten. Also, just give me single words such as eat, or smell, rather than a sentence. Can you give me an example of something that people do?

Phonemic fluency was elicited following the Controlled Oral Word Association Test (COWAT; Ruff *et al.* 1996). The verbatim instructions were:

> I'd like you to tell me as many different things as you can think of that begin with the letter 'F'. I don't want you to use the same word with different endings like eat, eating, eaten. And again, just give me simple words instead of a sentence. Can you give me an example of something that starts with the letter 'F'?

Participants were asked to generate a list of words beginning with the letters, F, A and S (in that order) for 1 min each. The tester transcribed verbal fluency responses during the session. The responses were audio-recorded for later verification.

Data analysis

The final score for each verbal fluency prompt was the total number of correct items produced, excluding perseverations and intrusions (words from other grammatical classes or neologisms). For statistical analyses, phonemic fluency total scores were divided by three (1 min each for F, A and S) to make these comparable with the animal and action fluency elicitation times. The number of clusters and perseverations were counted for each verbal fluency prompt. Clusters were defined as successively generated words that were either phonemically or semantically related (LeDoux *et al.* 2014; Troyer 2000). Phonemic relatedness was defined as words that began with the same letter (or first two letters for phonemic fluency), differed only by a vowel sound, rhymed or were homonyms. Semantic relatedness was defined as a paradigmatically or syntagmatically related response. Paradigmatically related words are typically from the same grammatical category (e.g., *cat–dog*, *lion–tiger*) and syntagmatically related words have a semantic association such that they often co-occur (e.g., *salt-shaker*). Perseverations were defined as the exact repetition of a previously generated response, including the example used in the instructions (Ruff *et al.* 1996). Thus, *snow, snowy* was not a perseveration but a phonemic cluster. For action fluency, repetitions of verbs with different nouns were considered perseverations (e.g., *fix house, fix car*). The reliability of identifying clusters and perseverations was obtained for 20% of randomly selected samples by another research assistant. Interrater reliability was very strong (Cohen's $\kappa = 0.92$; McHugh 2012). Differences were resolved by the decision of a third research assistant.

To analyze the influence of psycholinguistic variables, the frequency of occurrence in American English (SUBTLEX; Brysbaert and New 2009) and age of acquisition (AoA; Kuperman *et al.* 2012) of each response was noted. Whole-word frequency for each response (e.g., eat) was obtained by adding the lexeme frequencies of inflectional variants (e.g., *eat*, *eats*, *eating*, *eaten* and *ate*). The syllable length of each response was noted as a measure of phonological complexity.[1] After noting the frequency, AoA and syllable length of each response, the mean of each variable of each participant was calculated. Additionally, for action fluency, the number of light verbs produced were counted. Light verbs are semantically underspecified verbs that are highly frequent in English, take diverse noun complements and share the feature of frequently grammaticalizing cross-linguistically. The following nine verbs were identified as light verbs: *come*, *do*, *get*, *give*, *go*, *have*, *make*, *put* and *take* (Thorne and Faroqi-Shah 2016).

Results

The group verbal fluency scores are given in table 2 and results of the statistical analyses are summarized in table 3. Six PWA could not complete at least one verbal fluency task or produced no responses because of their aphasia severity. Individual PWA scores are listed in the appendix in the supplemental data online.

Number of correct responses

Standard (*z*) scores were computed for each verbal fluency task based on the neurotypical group's performance for that task. The number of correct responses and standard scores are plotted in figure 1. To address the first

Table 2. Verbal fluency scores and response analysis results

	Neurotypical		Aphasia	
	Mean	SD	Mean	SD
Animal fluency				
Correct responses	18.6	2.4	8.1	5.2
Clusters	5.2	1.6	1.8	1.4
Perseverations	0.54	0.9	0.5	0.9
Word frequency (per 50 million)	1834.5	480.8	3227.7	1830.5
Word frequency (log)	2.7	0.2	3.2	0.3
Age of acquisition (years)	5.2	0.6	4.3	0.6
Number of syllables (per word)	1.7	0.2	1.3	0.3
Action fluency				
Correct responses	17.2	5.5	4.6	4.0
Clusters	4.3	1.8	1.0	1.1
Perseverations	0.5	0.8	0.5	1.1
Word frequency (per 50 million)	18,760.3	17,167.7	52,924.8	75,145.9
Word frequency (log)	3.5	0.2	3.9	0.8
Age of acquisition (years)	4.7	0.5	4.8	1.2
Number of syllables (per word)	1.25	0.27	1.40	0.60
Proportion of light verbs	0.010	0.030	0.060	0.090
Phonemic fluency				
Correct responses	37.9	10.4	7.1	6.3
Clusters	6.2	2.8	0.8	1.1
Perseverations	0.6	0.8	0.25	0.5
Word frequency (per 50 million)	12,314.1	18,505.8	9156.2	14,064.5
Word frequency (log)	3.0	0.3	3.5	0.5
Age of acquisition (years)	6.5	0.8	4.9	0.8
Number of syllables (per word)	1.90	0.3	1.50	0.40

Note: Values for phonemic fluency are over 3 min (FAS).

Table 3. Statistically significant comparisons of a 2 (group) × 3 (verbal fluency task) analysis of variance (ANOVA)

	Statistical comparisons		
	Group (neurotypical versus PWA)	Task	Interaction
Total score	$F(1,198) = 339.1^{***}$	$F(2,198) = 13.1^{***}$	$F(2,198) = 26.7^{***}$
Mean difference (SE)	3.3(0.18)	Animal action $= -1.1(0.2)^{***}$	
		Animal phonemic $= -0.8(0.2)^{**}$	
Clusters	$F(1, 175) = 4.8^{*}$	$F(2, 175) = 19.8^{***}$	$F(2,175) = 14.8^{***}$
Mean difference (SE)	0.8(0.4)	Animal phonemic $= -1.6(0.3)^{***}$	
		Action phonemic $= -1.8(0.3)^{***}$	
Response frequency	$F(1, 180) = 48.1^{***}$	$F(2, 180) = 45.7^{***}$	
Mean difference (SE)	$-0.4(0.06)$	Animal action $= -0.74(0.08)^{***}$	
		Animal phonemic $= -0.25(0.07)^{**}$	
		Action phonemic $= 0.49\ (0.08)^{***}$	
Response age of acquisition	$F(1, 179) = 54.8^{***}$	$F(2, 179) = 33.4^{***}$	$F(2,179) = 16.9^{***}$
Mean difference (SE)	0.8(0.1)	Animal phonemic $= -0.9(0.13)^{***}$	
		Action phonemic $= -1\ (0.14)^{***}$	
Number of syllables	$F(1, 183) = 14.6^{***}$	$F(2, 183) = 17.3^{***}$	$F(2,183) = 11.6^{***}$
Mean difference (SE)	0.2(0.05)	Animal action $= 0.18(0.06)^{*}$	
		Animal phonemic $= -0.18(0.06)^{*}$	
		Action phonemic $= -0.37\ (0.06)^{***}$	

Notes: Perseverations did not yield any significant main effects or interactions and hence are not listed.
Post-hoc pairwise comparisons, unequal variances assumed: $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

aim of the study, we statistically compared standard scores using a two-way (2 groups × 3 tasks) univariate analyses of variance. There was a main effect of group (table 3): PWA scored 3.3 SD (standard deviations) below the mean score of neurotypical participants. There was also a main effect of task and a significant group-by-task interaction: compared with the neurotypical group, PWAs' animal fluency scores were 4.7 SD lower, while action and phonemic fluency scores were 2.4 and 2.9 SD lower than neurotypical group. In PWA showed that all

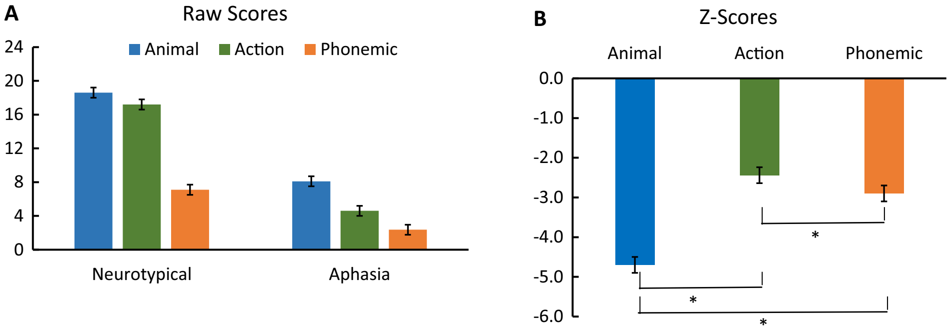

Figure 1. (A) Raw scores of neurotypical adults and persons with aphasia for each verbal fluency task; and (B) standard scores of persons with aphasia (PWA). Values are negative because PWA scored lower than the neurotypical comparison group. Error bars indicate standard error (SE) of the mean. Significant comparisons are indicated by $^{*}p < .05$. Raw scores were not used for between-group comparisons. [Colour figure can be viewed at wileyonlinelibrary.com]

three verbal fluency tasks differed significantly from one another (action versus phonemic: $t(27) = 2.8, p < .01$, animal versus phonemic: $t(27) = -3.8, p < .01$, action versus animal: $t(27) = 6.6, p < .001$).

In neurotypical adults, action fluency was modestly correlated with animal ($r_s = .4, p < .05$) and phonemic ($r_s = .3, p < .05$) fluency. Phonemic and animal fluency were not correlated ($r_s = .2, p = .2$). In PWA, action and animal fluency were highly correlated ($r_s = .8, p < .001$), but phonemic fluency was not correlated with either animal ($r_s = -.1, p = .6$) or action fluency ($r_s = -.37, p = .08$).

To examine if there were dissociations among verbal fluency tasks, paired comparisons (animal versus phonemic, animal versus action, action versus phonemic) of each PWA's scores were computed using Bayesian statistics (Crawford *et al.* 2010). This tests whether a PWA's scores on two verbal fluency tasks are significantly lower than those of the neurotypical group, and whether the standardized difference between the PWA's two verbal fluency scores is statistically significant. If two verbal fluency scores are significantly different, a classical dissociation means that only one of the verbal fluency score is worse than the neurotypical group, and a strong dissociation means both scores are lower than the neurotypical group (Crawford *et al.* 2003). The results are summarized in table 4 along with aphasia subtypes. There were a relatively even number of animal phonemic ($N = 10$) and animal action ($N = 11$) dissociations, but only two action-phonemic dissociations (all $t(39) > 1.9, p < .05$). Both action-phonemic dissociations were classical, characterized by within-normal action fluency performance.

Table 5 shows a breakdown of fluency scores by aphasia severity and classification (as measured by WAB-R). Given that verbal fluency is a timed task which could negatively impact the fluency scores of persons with non-fluent aphasia, we compared verbal fluency across non-fluent and fluent aphasia. Non-fluent aphasia was defined as a WAB-R fluency score between 1 and 4, and fluent aphasia as a WAB-R fluency score between 6 and 10. PWA with fluency scores of 5 were excluded because of the ambiguity of their fluency categorization. Non-fluent PWA did not differ significantly from fluent PWA in animal (Mann–Whitney $U = 11, p > .05$), action (Mann–Whitney $U = 19.5, p > .05$) or phonemic fluency (Mann–Whitney $U = 70.5, p > .05$).

Analysis of responses

There were a total of 3375 responses across the participant groups and verbal fluency tasks (animal, action and phonemic fluency: 744, 655 and 1478 responses respectively for neurotypical adults; 202, 105 and 191 responses respectively for PWA). To address the second goal of the study, the different response measures (clusters, word frequency etc.) were analyzed (figure 2 and tables 2 and 3).

Clusters

Given that there are more opportunities to produce clusters when there are more responses, analysis of covariance (ANCOVA) was performed to compare the difference between the neurotypical group and PWA, with the total number of correct responses as a covariate. There was a main effect of group showing that, on average, neurotypical individuals produced 0.7 more clusters than PWA. There was a main effect of task and a significant group-by-task interaction, showing that neurotypical adults produced more clusters than PWA only for phonemic fluency ($t(10) = 54.2, p < .001$, equal variances not assumed).

Perseverations

ANCOVA with number of correct responses as covariate showed no significant main effects of group ($F(1, 178)$

Table 4. Dissociations between the three verbal fluency tasks and the aphasia subtypes showing each pattern

Animal versus phonemic	Animal versus action	Action versus phonemic
Animal > phonemic, N = *1*	*Animal > action,* N = *0*	*Action > phonemic,* N = *2*
Anomic (1, classical)		Anomic (2, classical)
Animal < phonemic, N = *9*	*Animal < action,* N = *11*	*Action < phonemic,* N = *0*
Global (1), Broca's (6), conduction (1), anomic (1)	Broca's (6), conduction (1), TCM (1), anomic (2 strong, 1 classical)	

Note: The number of participants showing each pattern is given in parentheses; unless specified, numbers refer to strong dissociations. See the text for details. TCM, transcortical motor.

Table 5. Verbal fluency scores stratified by severity of aphasia and aphasia classification based on the Western Aphasia Battery—Revised

		Animal		Action		Phonemic	
Category	*N*	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Aphasia quotient							
< 39	2	0		0		5 (7.1)	0, 10[b]
40–60	6	2.5 (1.9)	1–6	1.2 (0.8)	1–2	8.7 (6.1)	0–17
60–80	7	6.8 (3)	1–10	2.8 (2.2)	0–5	4.3 (2.5)	0–7
81–100[a]	14	11.5 (4.4)	3–20	6.3 (4.4)	1–15	6.6 (7.5)	1–24
Aphasia subtypes							
Global	2	0		0		5 (7.1)	0, 10
Broca's/transcortical motor[c]	11	5.8 (4.8)	1–12	2 .4 (5)	0–4	7.6 (7.2)	0–19
Conduction	3	6 (4.2)	2–6	4 (2)	2–6	2.7 (6.1)	1–6
Anomic	13	10.9 (4.8)	3–20	6.3 (5)	0–15	6.5 (7.2)	0–24
Aphasia fluency[d]							
Non-fluent	7	3.8 (2.5)	1–7	1.6 (1.7)	1–4	8.1 (5.7)	0–17
Fluent	16	10.4 (4.9)	1–20	5.8 (4.4)	0–15	5.4 (6.4)	0–24

Notes: [a] No PWA scored higher than 95.
[b] Only two participants in this category.
[c] Broca's and transcortical motor aphasia are combined because of similarities in their clinical presentation and fluency.
[d] Participants with a fluency score of 5 are excluded. See the text for details.

$= 0.05$, $p = .8$), task ($F(2,178) = 0.07$, $p = .9$), and group-by-task interaction ($F(2,178) = 1.1$, $p = .3$).

Word frequency

Analysis of variance (ANOVA) of logarithmically transformed frequencies (Baayen and Milin 2010) revealed a main effect of group, in which PWAs' responses had higher frequency of occurrence than responses produced by neurotypical individuals. There was a significant main effect of task, showing that responses for action fluency had the highest frequency (mean (SE) = 3.7 (0.05)), followed by phonemic fluency (mean (SE) = 3.2 (0.05)), and with lowest frequencies for animal fluency (mean (SE) = 2.9 (0.05)). There was no significant group-by-task interaction ($F(2,180) = 0.6$, $p = .6$), showing that both groups had a similar effect of task.

Age of acquisition

There was a main effect of group, main effect of task and a significant group-by-task interaction: PWAs' responses had an earlier age of acquisition than neurotypical adults for animal ($t(47.1) = 5.5$, $p < .001$) and phonemic fluency ($t(48.4) = 7.5$, $p < .001$), but not for action fluency ($t(24) = 0.01$, $p = .9$, equal variances not assumed).

Syllable number

A main effect of group, main effect of task with a group-by-task interaction. PWAs' responses had a lower number of syllables than neurotypical adults for animal ($t(38.5) = 5.4$, $p < .001$), and phonemic fluency ($t(39.8) = 4.2$, $p < .001$), but not for action fluency ($t(20.7) = -1.6$, $p = .1$, equal variances not assumed).

Light verbs for action fluency

PWA produced significantly more light verbs than neurotypical adults ($t(21.7) = 2.2$, $p < .05$ equal variances not assumed), as shown in table 2.

To summarize, PWA performed worse than neurotypical participants across all verbal fluency tasks, and animal fluency scores were farthest from neurotypical performance. PWA produced lexically simpler responses than their neurotypical peers, characterized by higher word frequency, earlier age of acquisition, and shorter word length for animal and phonemic fluency, but not action fluency (except frequency). The only measure

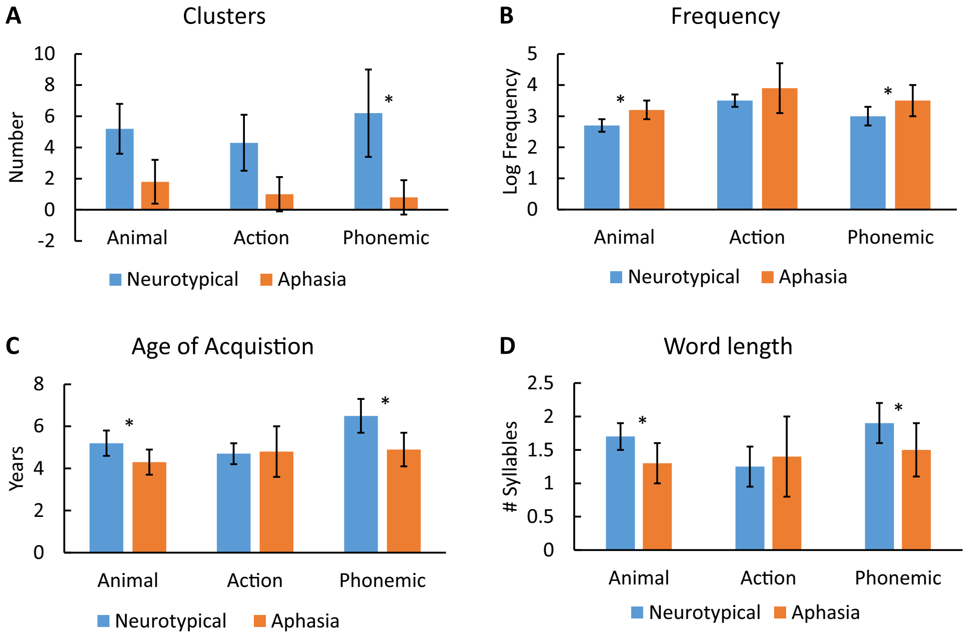

Figure 2. Qualitative analyses of responses of neurotypical adults and persons with aphasia for each verbal fluency task. Error bars indicate standard deviation (SD). (A) Mean number of clusters; (B) logarithm of word frequency of responses (per 50 million words); (C) age of acquisition (years); and (D) word length. Perseverations are not plotted because there were no significant group or task differences. [Colour figure can be viewed at wileyonlinelibrary.com]

that did not differentiate the two groups is the number of perseverations.

Variables influencing verbal fluency performance

The third goal of the study was to identify how linguistic (WAB-R, BNT etc.) and response-related (clusters, frequency etc.) variables influence verbal fluency performance. Correlation coefficients between variables and verbal fluency scores were used to examine multicollinearity (defined as a correlation $> .8$; Katz 2006) and for inclusion in the linear regression analysis (correlation with verbal fluency $> .2$) (table 6). Separate simple linear regression analyses were conducted for each participant group and verbal fluency task, where all predictor variables were simultaneously entered into the model. None of the regression models was statistically significant and, hence, the linear regressions were repeated with only response variables: the number of clusters, perseverations, log frequency, AoA and syllable number (table 7).

Neurotypical adults

The regression models for animal, action and phonemic fluency were statistically significant (animal: R^2 change $= 0.44$, $F(5,29) = 4.5$, $p < .01$, mean square $= 18.9$; action: R^2 change $= 0.42$, $F(5,31) = 4.5$, $p < .01$, mean square $= 94.3$; phonemic: R^2 change $= 0.55$, $F(5,33) = 8$, $p < .001$, mean square $= 453.9$). For all three verbal fluency tasks, the only significant predictor variable was the number of clusters ($p < .01$), indicating that for every additional cluster, the animal, action and phonemic fluency scores increased by 0.9, 1.5 and 12.6 respectively.

Persons with aphasia

Animal and action fluency, but not phonemic fluency, correlated significantly with language measures (WAB-R AQ, VNT, BNT) (table 4). The regression models of action and animal fluency with language measures were significant (animal: $R^2 = 0.86$, $F(5,18) = 22.7$, $p < .001$, mean square $= 104.9$; action: R^2 change $= 0.68$, $F(5,11) = 4.7$, $p < .05$, mean square $= 31.9$; phonemic: R^2 change $= 0.34$, $F(5,18) = 1.9$, $p = .14$, mean square $= 59.8$). For both animal and action fluency, the number of clusters was a significant predictor ($p < .01$), with each additional cluster, the fluency scores increased by 2.5 and 3.1 respectively. The number of syllables also predicted animal fluency scores ($p < .01$), PWA who produced longer words had an eight-point increase in animal fluency score.

Discussion

This study is the first to report performance across three verbal fluency tasks in PWA. We also conducted novel

Table 6. Correlations between verbal fluency and language and cognitive measures for neurotypical and aphasic groups

	Animal		Action		Phonemic	
	Neurotypical	Aphasia	Neurotypical	Aphasia	Neurotypical	Aphasia
Aphasia Quotient (WAB-R)	.52**	0.7*	0.25	.55*	0.14	−0.31
Boston Naming Test	0.26	0.66*	0.4	.56*	0.49	−0.25
Verb Naming Test	−0.005	0.61*	0.12	.62**	−0.15	−0.33
MMSE	0.05	0.48*	.34*	.46*	0.17	−0.19
RCPM	0.27	0.35	0.25	0.38	0.33	−0.06

Notes: $^{*}p < .05$, $^{**}p < .01$.
MMSE, Mini Mental State Examination (Folstein *et al.* 1975); RCPM, Raven's Colored Progressive Matrices (Raven and Court 1998).

Table 7. Summary of regression analyses

Group and task	Predictor by task	B	SE B	β
Neurotypical				
Animal fluency	Clusters	0.9**	0.2	0.58
	Perseverations	0.6	0.4	0.22
	Frequency (log)	−2.5	3.3	−0.2
	Age of acquisition	0.8	1	0.17
	Syllable number	0.6	2.1	0.05
Action fluency	Clusters	1.4**	0.4	0.5
	Perseverations	−0.68	0.9	0.5
	Frequency (log)	2.6	3.6	0.12
	Age of acquisition	3.8	2.1	0.32
	Syllable number	1.2	2.8	0.06
Phonemic fluency	Clusters	2.6**	0.46	0.7
	Perseverations	0.14	1.4	0.01
	Frequency (log)	3.6	5.5	0.11
	Age of acquisition	2.4	2.1	0.18
	Syllable number	3.2	5.8	0.09
Persons with aphasia				
Animal fluency	Clusters	2.6***	0.5	0.67
	Perseverations	−0.59	0.5	−0.11
	Frequency (log)	−1.6	2.4	−0.1
	Age of acquisition	−1.9	1.2	−0.25
	Syllable number	8.1**	2.5	0.5
Animal fluency	Clusters	3.1**	0.7	0.8
	Perseverations	−0.32	0.56	−0.1
	Frequency (log)	−1.3	1.5	−0.23
	Age of acquisition	−0.94	1.1	−0.28
	Syllable number	1	1.5	0.17
Phonemic fluency	Clusters	2.4*	1.1	0.43
	Perseverations	−4.5	2.4	−0.4
	Frequency (log)	−0.94	2.9	−0.08
	Age of acquisition	0.15	1.5	0.02
	Syllable number	−5.6	3.6	−0.36

Note: $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

qualitative analyses of the responses by examining variables that reflect lexical retrieval difficulties. The main findings of the study are that PWA scored lower than neurotypical adults across all three verbal fluency tasks. The difference between groups was greatest for animal fluency and least for action fluency. PWA produced fewer clusters than neurotypical adults, but there was no difference in the number of perseverations. PWAs' responses were more lexically accessible, characterized by higher frequency of occurrence and earlier age of acquisition. Their responses were also phonologically simpler, as measured by the number of syllables per word. Finally, the number of clusters significantly predicted overall verbal fluency performance for both participant groups. The implications of these results are discussed below.

Comparison across verbal fluency tasks

The finding of lower verbal fluency performance in PWA compared with neurotypical adults is consistent with prior studies of PWA (Adams *et al.* 1989, Bose *et al.* 2017, Kiran *et al.* 2014) and of a variety of neuropsychiatric diagnoses (reviewed in Thiele *et al.* 2016). Even mildly impaired PWA (WAB-R AQ > 80) demonstrated diminished verbal fluency scores (table 5), indicating the sensitivity of verbal fluency measures to the presence of mild aphasia. Although all three verbal fluency measures showed diminished performance, only the semantic fluency measures were strongly correlated with language measures, including WAB-R AQ, BNT and VNT (table 6). Thus, semantic fluency performance of PWA should be interpreted within the broader context of their language abilities. The relationship between animal fluency and aphasia severity was reported by Roberts and LeDorze (1994). To our knowledge, there are no prior reports of the interplay between aphasia severity and action or phonemic fluency. It is noteworthy that semantic fluency did not show a sensitivity to grammatical category: animal (and action) fluency correlated with *both* noun (BNT) and verb (VNT) naming. That is, semantic fluency captured overall lexical abilities rather than grammatical category specific retrieval. This implies that, in PWA, animal and action fluency have limited utility as proxy tasks for detecting noun–verb dissociations, although animal versus action fluency differences have been found in neurocognitive conditions with subtle language deficits, such as early stages of Parkinson's disease (Piatt *et al.* 1999).

Phonemic fluency did not correlate with language impairment in PWA (table 6). A similar lack of association between phonemic fluency performance and word retrieval scores was found in persons with TBI

(Bittner and Crowe 2007). This is presumably because phonemic fluency relies more on executive processes and less on the integrity of language networks (Baldo *et al.* 2006, 2010). Phonemic fluency is also less likely to decline with age (Elgamal *et al.* 2011, Stolwyk *et al.* 2015). The insensitivity of phonemic fluency performance to aphasia severity and normal aging makes it a particularly sensitive measure of executive functioning in individuals with aphasia.

Of the three verbal fluency tasks, action fluency was least impaired in PWA, even though verb retrieval is generally considered to be more challenging in PWA (Matzig *et al.* 2009). One possible explanation for this pattern is that PWA used more light verbs than neurotypical adults, thus improving their total score. As will be discussed below, light verbs are more frequent than other verbs, making them more accessible for PWA, especially when there are no semantic or syntactic constraints on verb choice.

Comparison across aphasia subtypes

Examination of verbal fluency across aphasia subtypes showed no clear dissociations among animal, action and phonemic fluency for any subtype of aphasia (tables 4 and 5). In the present study, animal fluency was more impaired than phonemic fluency irrespective of aphasia subtype. Notably, persons with Broca's aphasia did not perform worse on phonemic fluency compared with animal fluency, contrary to the 'double dissociation' reported for aphasia (Baldo *et al.* 2010). There are several possible reasons for these seemingly discrepant findings. First, aphasia is primarily a language impairment characterized by weakened lexical networks. Thus, a verbal fluency task that demands fine-grained selection between highly related words (e.g. animals) is more severely impaired than a verbal fluency task in which there is more flexibility in choice of words (phonemic and action fluency). The explanation that word retrieval ability is not the primary determinant of phonemic fluency performance, is supported by the absence of a significant correlation between phonemic fluency and naming (BNT, VNT) or aphasia severity (WAB-R AQ) in this study. Secondly, prior studies have typically compared raw scores across verbal fluency tasks, sometimes without using neurotypical performance as the basis of comparison. These practices significantly increase the chances of finding a dissociation when there is none (type 1 error; Crawford and Garthwaite 2006). In the present study, we adopted a statistically conservative Bayesian approach that compares standard scores (Crawford *et al.* 2010) based on neurotypical performance. Table 2 shows that neurotypical individuals had lower phonemic fluency scores and more variable action fluency scores, justifying the use of standard scores. Finally, the phonemic–semantic fluency dissociation in prior research is somewhat equivocal: phonemic fluency is not always impaired in unilateral and bilateral frontal TBI (Jurado *et al.* 2000), and did not differentiate frontal versus temporal lesions in TBI (Chapados and Petrides 2013) and degenerative conditions (Clark *et al.* 2014, Davis *et al.* 2010, Marczinski and Kertesz 2006). Phonemic fluency has been associated with other lesions, including subcortical (Baldo *et al.* 2006, Clark *et al.* 2014) and medial frontal (Troyer *et al.* 1998) lesions. In sum, the present study did not find support for a phonemic–semantic dissociation in Broca's aphasia. Given that lesion-symptom mapping was outside the scope of the present study, further research is needed to confirm whether phonemic and semantic fluency are statistically dissociated in isolated frontal versus temporal lesions.

Analysis of responses

The present study reported novel qualitative response analyses, showing that, on average, PWAs' verbal fluency responses include words that are more frequent, have an earlier age of acquisition and have shorter syllable length. The facilitative influence of word frequency and age of acquisition have been reported on picture naming and word repetition in PWA (Bastiaanse *et al.* 2016, Brysbaert and Ellis 2016, Kittredge *et al.* 2008, Nozari *et al.* 2010). The present study contributes by reporting frequency and age-of-acquisition effects on verbal fluency, which is a more open-ended and time-constrained task, with greater demands on cognitive control. Word frequency and age of acquisition tend to be highly correlated, and prior studies have found that the influence of word frequency is reduced after accounting for age of acquisition effects (Bastiaanse *et al.* 2016, Morrison *et al.* 1992). Nevertheless, during word production, both frequency and age of acquisition effects are presumed to arise at the stage of post-semantic lexical access (e.g., Nozari *et al.* 2010). In fact, the absence of a frequency effect is indicative of a semantic deficit (Mirman and Britt 2014). That is, this group of PWA demonstrated a pattern of producing responses that are lexically more accessible, likely because lexical access was compromised in their overall weakened lexical–semantic network. The higher proportion of light verbs in PWAs' action fluency responses could also be explained by lexical accessibility. Light verbs tend to have higher word frequency and earlier age of acquisition, making them more lexically accessible than other verbs. Thus, in spite of being syntactically more complex (Thorne and Faroqi-Shah 2016), light verbs are more accessible under the time-constrained, open-ended demands of action fluency.

Another finding that points to weak lexical–semantic networks in PWA is their smaller cluster size compared with neurotypical adults, which is consistent with prior findings in aphasia (Baldo *et al.* 2010, Bose *et al.* 2017, Kiran *et al.* 2014). The smaller cluster size is indicative of less success with lexical search strategies, presumably due to weakened connections between words in the mental lexicon. In fact, regression analyses showed that cluster size was the only significant predictor of performance for all three verbal fluency tasks.

In addition, in animal and phonemic fluency, PWAs' responses had a shorter syllable length compared with neurotypical adults. While syllable planning is considered a post-lexical phonological process (Roelofs 1997), interactive models of word retrieval accommodate an interplay between phonological and lexical–semantic processes (e.g., Kittredge *et al.* 2008). Thus, in a timed task such as verbal fluency, PWA may prioritize production of words that are both lexically accessible and phonologically simpler.

Finally, this study sheds light on the executive functioning abilities of PWA, as revealed by verbal fluency performance. PWA did not show evidence of difficulty in inhibitory control, as evidenced by negligible occurrence of perseverations. Like neurotypical adults, PWA used clustering strategies, although their cluster size was smaller. The fact that PWA produce clusters at all shows that they are able to utilize search strategies similar to neurotypical adults. It is important to point out that verbal fluency performance was unrelated to non-verbal cognitive abilities, as measured by RCPM (table 6).

Conclusions

Verbal fluency is a very short, yet highly sensitive test of verbal and cognitive functioning that is widely used in neuropsychological assessment, clinical practice and research. This study contributes to the literature on verbal fluency by reporting data on three verbal fluency tasks across subtypes and severity of aphasia. This study shows that verbal fluency is impaired in aphasia, even in mild aphasia. Animal fluency is the most vulnerable verbal fluency measure and action fluency is the least impaired. The high use of light verbs likely boosts action fluency scores in PWA. Animal and action fluency are heavily influenced by the severity of language impairment. These two tasks have little utility in identifying verb–noun dissociations because both are correlated with picture naming of nouns *and* verbs. Phonemic fluency is unaffected by severity of language impairment, and hence is a reliable indicator of cognitive control in aphasia. Aphasia subtypes did not show any distinct differentiating patterns of performance. Analysis of responses revealed that PWA produced more frequent, earlier acquired, and shorter words than neurotypical adults, especially for animal and phonemic fluency. This is suggestive of a strategy to circumvent impaired lexical access. This study shows the importance of psycholinguistic analysis of verbal fluency responses, which can inform us about the integrity of the lexical system and the ability to utilize word generation strategies in PWA.

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Note

1. Phonological complexity includes parameters such as number of syllables, phonemes and consonant clusters.

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Appendix: Individual participants' demographic information and language scores. Blank cells indicate that the participant was unable to complete the task

ID	Age years	Educ years	WAB-R AQ	Aphasia Type	BNT	VNT	Action	Animal	FAS
Max Score	-	-	100	-	60	22	-	-	-
MMA01	43	17	93.8	Anomic	47	18	8	16	9
MMA02	69	15	87.6	Anomic	14	14	1	3	10
MMA03	46	16	85.1	Anomic	34	14	5	11	4
MMA05	66	16	77.7	Anomic	33	14	5	7	
MMA06	69	15	45.8	Broca	20	8	1	6	14
MMA08	56	18	49.5	Broca	31	7	2	3	17
MMA09	61	20	89.8	Anomic	56	22	11	15	24
MMA10	56	14	12.7	Global	0	0	0		0
MMA11	70	16	91.4	Anomic	49	15	2	7	0
MMA12	54	14	89.6	Anomic	41	22	10	9	1
MMA13	42	18	62.9	Broca	18	16	4	7	7
MMA14	53	15	49.4	Broca	34	17	1	3	6
MMA15	65	20	65.9	Broca	28	13	4	6	0
MMA16	67	12	53.8	Conduction	8	16	2	1	6
MMA17	84	12	81.6	Conduction	30	14	4	11	1
MMA18	73	20	53.7	Broca	18	4	0	1	9
MMA19	49	15	82	Conduction	37	21	6		1
MMA20	58	16	94.8	Anomic	44	20	6	13	5
MMA21	58	15	20	Global					10
MMA22	37	16	93.3	Anomic	47	22		11	3
UMA01	37	16	89.2	Anomic	41	19	15	20	3
UMA02	37	17	92.5	Anomic	36	20	1	7	13
UMA03	80	13	89.2	Anomic	57	21	11	15	0
UMA04	81	18	80.4	Anomic	30	18	0	10	5
UMA05	72	18	49.2	Broca	7	6		1	0
UMA06	87	12	61.9	Broca	18	11		1	6
UMA07	73	13	74.6	Broca	37	18	0	10	3
UMA10	52	20	81.6	TCM	43	12	2	12	19
UMA11	51	13	78.9	TCM	47	18	4	7	5