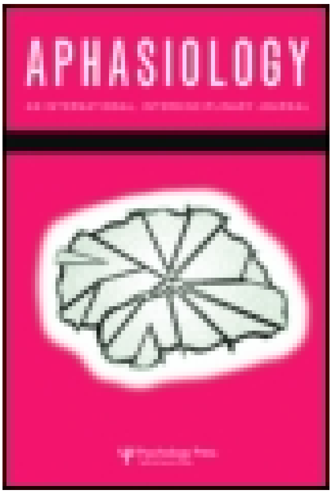

Aphasiology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/paph20

Phonological facilitation effects on naming latencies and viewing times during noun and verb naming in agrammatic and anomic aphasia

Jiyeon Lee[a] & Cynthia K. Thompson[bcd]
[a] Department of Speech, Language, and Hearing Sciences, Purdue University, West Lafayette, IN, USA
[b] Department of Communication Sciences and Disorders, Northwestern University, Evanston, IL, USA
[c] Cognitive Neurology and Alzheimer's Disease Center, Northwestern University, Evanston, IL, USA
[d] Department of Neurology, Northwestern University, Evanston, IL, USA
Published online: 27 Apr 2015.

To cite this article: Jiyeon Lee & Cynthia K. Thompson (2015): Phonological facilitation effects on naming latencies and viewing times during noun and verb naming in agrammatic and anomic aphasia, Aphasiology, DOI: 10.1080/02687038.2015.1035225

To link to this article: http://dx.doi.org/10.1080/02687038.2015.1035225

Aphasiology, 2015
http://dx.doi.org/10.1080/02687038.2015.1035225

Phonological facilitation effects on naming latencies and viewing times during noun and verb naming in agrammatic and anomic aphasia

Jiyeon Lee[a]* and Cynthia K. Thompson[b,c,d]

[a]*Department of Speech, Language, and Hearing Sciences, Purdue University, West Lafayette, IN, USA;* [b]*Department of Communication Sciences and Disorders, Northwestern University, Evanston, IL, USA;* [c]*Cognitive Neurology and Alzheimer's Disease Center, Northwestern University, Evanston, IL, USA;* [d]*Department of Neurology, Northwestern University, Evanston, IL, USA*

(*Received 14 October 2014; accepted 23 March 2015*)

Background: Phonological priming has been shown to facilitate naming in individuals with aphasia, as well as healthy speakers, resulting in faster naming latencies. However, the mechanisms of phonological facilitation (PF) in aphasia remain unclear.
Aims: Within discrete vs. interactive models of lexical access, this study examined whether PF occurs via the sub-lexical or lexical route during noun and verb naming in agrammatic and anomic aphasia.
Methods & Procedures: Thirteen participants with agrammatic aphasia and 10 participants with anomic aphasia and their young and age-matched controls (n = 20/each) were tested. Experiment 1 examined noun and verb naming deficit patterns in an off-line confrontation naming task. Experiment 2 examined PF effects on naming both word categories using eyetracking priming paradigm.
Outcomes & Results: Results of Experiment 1 showed greater naming difficulty for verbs than for nouns in the agrammatic group, with no difference between the two word categories in the anomic group. For both participant groups, errors were dominated by semantic paraphasias, indicating impaired lexical selection. In the phonological priming task (Experiment 2), young and age-matched control groups showed PF in both noun and verb naming. Interestingly, the agrammatic group showed PF when naming verbs, but not nouns, whereas the anomic group showed PF for nouns only.
Conclusions: Consistent with lexically mediated PF in interactive models of lexical access, selective PF for different word categories in our agrammatic and anomic groups suggest that phonological primes facilitate lexical selection via feedback activation, resulting in greater PF for more difficult (i.e., verbs in agrammatic and possibly nouns in anomic group) lexical items.

Keywords: aphasia; eyetracking; phonological priming; lexical access; noun and verb naming

Introduction

Naming deficits, pervasive in aphasic speakers, often are improved under phonological priming conditions, i.e., with primes that are phonologically related to the to-be-named item. However, the mechanisms of this phonological facilitation (PF) effect are not clearly understood. Although various models of naming posit different levels of representation, both meaning-based (e.g., *lexical selection*) and form-based (e.g., *phonological encoding*) processes are required across models (Bock & Levelt, 1994; Kempen & Hujibers, 1983;

*Corresponding author. Email: lee1704@purdue.edu

Levelt, Roelofs, & Meyer, 1999; Rapp & Goldrick, 2000). The time course and the flow of information between these two processes, however, differ for discrete and interactive two-stage models. Discrete two-stage models assume distinctive processes at each level, occurring in serial, feed-forward order. Thus, lexical selection, in which a whole word representation is selected together with its syntactic information ("lemma") based on activation of semantic features, occurs *before* phonological encoding, which involves activation of phonemes (Levelt, 1989, 2001; Levelt et al., 1999; Schriefers, Meyer, & Levelt, 1990). On the other hand, in interactive two-stage models, these processes are interconnected, allowing spreading activation of information within and between them. Thus, lexical selection occurs *in parallel with* phonological encoding, resulting in phonological encoding (at least to some degree) of the entire set of activated lemma candidates. In addition, *feedback* from activated phonological information to the lexical level occurs, which may affect lexical selection process (Dell, 1986; Dell & O'Seaghdha, 1992; Dell & Reich, 1981; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997; Foygel & Dell, 2000; Stemberger, 1985).

These distinctions between discrete and interactive models predict sub-lexical and lexically mediated mechanisms of PF, respectively, as shown in Figure 1. In the discrete models, when speakers are primed with a phonologically related word, information from the prime boosts naming because shared phonemes between prime and target words reduce the time required to activate the target-word phonemes during phonological encoding of the already selected lexical item, i.e., *sub-lexical PF* (Levelt et al., 1999; Meyer & Schriefers, 1991; Meyer & van der Meulen, 2000; Schriefers et al., 1990). In contrast, in interactive models, phonological primes not only facilitate selection of target phonemes at the phonological level, but they also facilitate lexical selection via feedback from shared phonological units, i.e., *lexically mediated PF* (Damian & Martin, 1999; Dell & O'Seaghdha, 1992; Roelofs, Meyer, & Levelt, 1996). As a result, activation of the target lemma becomes stronger and selected faster compared to its semantically related competing lemmas, which do not share phonological information with the prime.

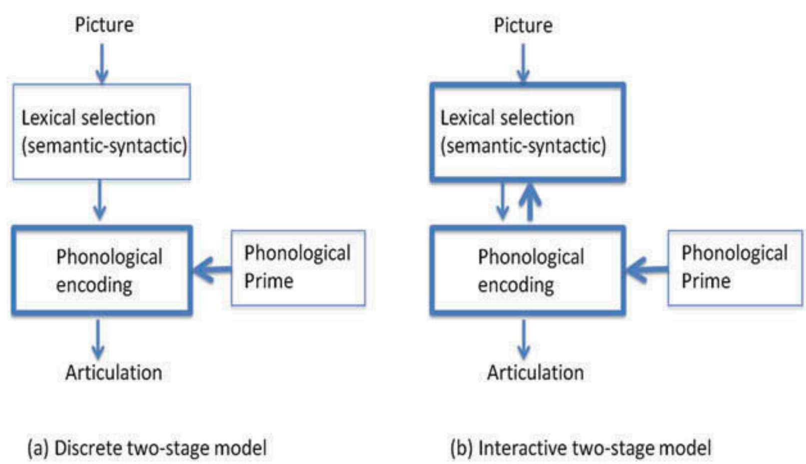

Figure 1. The mechanisms of phonological facilitation: sub-lexical PF within the discrete models (a) and lexically-mediated PF within the interactive models (b). The bolded boxes and arrows indicate the level(s) and directions of PF. Only the interactive models allow for PF to affect lexical selection via feedback from the phonological encoding level. [To view this figure in colour, please see the online version of this Journal.]

Picture–word interference studies in normal speakers, requiring participants to name pictures while ignoring visual or auditory distractor (prime) words presented at various stimulus-onset asynchronies (SOAs), provide support for both models. Some studies show nonoverlapping semantic interference and PF effects, supporting the discrete and serial processes of lexical selection and phonological encoding: semantic distractors (*goat* for *sheep*) increase (slow) naming latencies when presented prior to, but not after, the to-be-named pictures, but phonological distractors (*sheet* for *sheep*) result in decreased naming latencies when presented simultaneously with or shortly after, but not before, the picture (Levelt et al., 1991; Meyer & Schriefers, 1991; Schriefers et al., 1990). Other picture–word interference studies, however, have found overlapping semantic interference and PF effects across SOAs (e.g., presented before, simultaneously with, or after target pictures), consistent with interactive models of lexical access (Damian & Martin, 1999; Starreveld, 2000; Starreveld & La Heij, 1996). In addition, distractor words presented at earlier SOAs (e.g., 0 ms) that are both semantically and phonologically related to the target picture name result in reduced semantic interference effects compared to semantically related distractors, suggesting that the feedback information from the phonologically related distractors to the lexical level attenuates semantic competition (Damian & Martin, 1999). However, it should be noted that in some circumstances, phonological primes have been shown to be inhibitory, creating phonological competition during phoneme selection when target item phonemes reactivate prime item phonemes (see Discussion for more details; Columbo, 1986; Lupker & Columbo, 1994; O'Seagdha & Marin, 2000).

In addition to affecting naming latency, PF also is reflected in speakers' viewing times to the picture in eyetracking studies. Meyer and van der Meulen (2000) monitored gaze duration in Dutch-speaking college students as they named pairs of pictured objects (e.g., *the bed and the spoon*) presented simultaneously with auditory primes, either phonologically related or unrelated to the first object (*belt-bed, pot-bed*, respectively). Results showed significantly shorter viewing times to the first object in the related compared to the unrelated prime condition, reflecting PF. This is because speakers' eye gaze to objects precedes naming, reflecting time required for lexical selection and phonological encoding for the object (Griffin, 2001; Griffin & Bock, 2000; Meyer, Sleiderink, & Levelt, 1998).

Both discrete and interactive two-stage models of lexical access have been used to characterise naming deficits in aphasia. For example, cases of aphasia have been reported who produce semantic or whole-word (lexical) errors, but almost no phonological or nonword errors, suggesting impaired lexical selection (Cuetos, Aguado, & Caramazza, 2000; Gainotti, Silveri, Villa, & Miceli, 1986; Hillis, Rapp, Romani, & Caramazza, 1990; Lambon Ralph, Sage, & Roberts, 2000; Rapp & Goldrick, 2000; (PW)). Conversely, others have been reported whose naming errors are primarily sub-lexical (phonological, nonwords), suggesting impaired phonological encoding (Caramazza, Miceli, & Villa, 1986; Caramazza, Papagno, & Ruml, 2000; Hillis, Boatman, Hart, & Gordon, 1999; Kay & Ellis, 1987; Rapp & Goldrick, 2000; (CSS); Wilshire & McCarthy, 1996). Some aphasic speakers also produce a variety of naming errors including nonword, semantic, formal (i.e., real word responses, which overlap phonologically with target words such as *pore* for *core* and *barn* for *darn*, Rapp & Goldrick, 2000, p. 467), as well as *mixed errors* (i.e., semantically and phonologically related errors such as *rat* for *cat*), reflecting feedback from phonological to lexical levels (Dell & Reich, 1981; Martin, Gagnon, Schwartz, Dell, & Saffran, 1996). Based on aphasic naming error patterns as well as subsequent computational error simulations, some researchers have suggested impaired spreading activation between processing levels as a major source of word retrieval failure in aphasia, secondary to increased noise and decay rate of information in the lexical network (Dell et al., 1997; Laine & Martin, 1996; Martin et al., 1996; see also Lambon Ralph et al., 2000).

Selective impairments between nouns and verbs have also been reported in individuals with aphasia. For example, individuals with agrammatic aphasia show greater difficulty retrieving verbs compared to nouns in both structured naming tasks and narrative speech, whereas those with Wernicke's or anomic aphasia show relatively greater difficulty with nouns compared to verbs in some conditions (Bates, Chen, Tzeng, Li, & Opie, 1991; Caramazza & Hillis, 1990; Chen & Bates, 1998; Hyun, 2003; Kim & Thompson, 2000; Luzzatti & Chierchia, 2002; McCarthy & Warrington, 1985; Miceli, Silveri, Villa, & Caramazza, 1984; Myerson & Goodglass, 1972; Saffran, Schwartz, & Marin, 1980; Thompson et al., 1995; Zingeser & Berndt, 1988, 1990). These dissociations have been attributed to impairments in retrieving category-specific semantic–syntactic properties, implying a deficit at the level of lexical selection. However, not all studies report clear distinctions between word categories and aphasia types (Berndt, Mitchum, Haendiges, & Sandson, 1997a, 1997b; Jonkers & Bastiaanse, 1998; Kohn, Lorch, & Pearson, 1989; Williams & Canter, 1987). For instance, Williams and Canter (1987) reported the results of an off-line naming study indicating that retrieving verbs is more impaired than retrieving nouns across different aphasia types. Zingerser and Berndt (1990) also found that their participants with anomic aphasia were equally impaired between nouns and verbs in a variety of tasks, except for naming to definitions in which they produced verbs better than nouns.

Phonological priming has been used to elucidate the underlying mechanisms of lexical processing in aphasia, albeit few studies of this type have been reported. Findings from lexical decision tasks have shown that the mechanisms of PF during lexical access may be differentially affected in different types of aphasia (Baum, 1997; Gordon & Baum, 1994; Milberg, Blumstein, & Dworetzky, 1988). Gordon and Baum (1994), for example, reported that both control and nonfluent participants showed faster reaction times in a lexical decision task when preceded by a rhyme prime, compared to a non-rhyme prime; however, fluent aphasic participants did not show a rhyme facilitation effect. Interestingly, both nonfluent and fluent aphasic groups were able to judge rhyme pairs successfully in a rhyme judgment task, indicating that despite intact phonological input and sub-lexical processing in both aphasic groups, fluent aphasic participants are impaired in using phonological information to access the lexical entries.

Very few studies have examined phonological priming in object naming tasks in aphasia, yielding various findings (Hashimoto & Thompson, 2009; Mack et al., 2013; Wilshire, Keall, Stuart, & O'Donnell, 2007; Wilshire & Saffran, 2005). In a visual picture–word interference study by Hashimoto and Thompson (2009), a larger than normal PF effect was found in individuals with various types of stroke-induced aphasia who were impaired in phonological encoding, suggesting that primes exhibit greater impact on an impaired compared to an unimpaired system. Mack et al. (2013), in another visual–picture word interference study, found near normal vs. prolonged PF in logopenic vs. agrammatic variants of primary progressive aphasia, suggesting the time course of PF may be different depending on deficits specific to aphasia type. More relevant to the current study, Wilshire and Saffran (2005), using an auditory priming paradigm, reported that two participants with anomic aphasia showed selective facilitation effects to begin-related vs. end-related phonological primes depending on the nature of their naming deficits, while these two types of primes were equally facilitatory for controls (Meyer & Schriefers, 1991). One patient, I.G., whose profile was consistent with a lexical selection deficit, benefited from begin-related primes only. Conversely, G.L. whose phonological encoding was impaired benefited from end-related primes but not from begin-related primes. Assuming sequential activation of phonemes within the interactive model of lexical access, it was argued that begin-related phonological primes are more likely to facilitate lexical selection via feedback activation to the lemma level, thus, benefiting the patient with lexical selection deficits more than end-related primes. In Wilshire et al. (2007), this idea that phonological primes affect lexical selection was further supported by another anomic patient, N.P., who showed a semantic facilitation effect at SOA 0 ms (prime presented simultaneously with the target) in an auditory picture–word task due to his significantly delayed semantic activation. N.P. also showed PF with phonologically related words presented at SOA 0 ms, indicating that phonological primes activate lexical representation via feedback even before semantic processing is complete.

The purpose of the present study was to examine the mechanisms of PF during noun and verb naming in individuals with agrammatic and anomic aphasia. Aphasic participants' word-category naming deficits (i.e., nouns and verbs) were first examined in an off-line confrontation naming task in Experiment 1. We hypothesised that the agrammatic group would show greater verb, compared to noun, naming deficits, whereas the opposite pattern was predicted for the anomic group, in keeping with previous observations of word-category naming deficits (Bates et al., 1991; Kim & Thompson, 2000; Luzzatti & Chierchia, 2002; McCarthy & Warrington, 1985; Miceli et al., 1984; Zingeser & Berndt, 1988). In Experiment 2, a phonological priming task, coupled with an eyetracking paradigm, was used to examine PF effects on naming by word category. It was predicted that if phonologically related primes serve to boost phonological encoding after lexical selection is completed (consistent with sub-lexical PF within discrete two-stage models), PF effects for both nouns and verbs would be seen in both aphasic groups, regardless of naming deficit patterns observed in Experiment 1. However, if phonological priming facilitates lexical selection via feedback mechanisms (consistent with lexically mediated PF within interactive models of naming), PF was expected to interact with word-category naming impairments, resulting in differential patterns of PF between the agrammatic and anomic groups, as reflected in naming latency. That is, the agrammatic group, with verb naming deficits, was predicted to show greater PF (i.e., faster naming with phonologically related versus unrelated primes) effects for verbs compared to nouns because feedback activation from related primes would boost selection of impaired lexical items to a greater extent than less impaired lexical items. Conversely, the anomic group was expected to show PF for nouns (the impaired word class), but not for verbs. In addition, using eyetracking in Experiment 2, we examined whether aphasic participants' viewing times would reflect PF effects, as shown in young normal speakers in Meyer and van der Meulen (2000). This measure is particularly relevant to examining naming ability in people with aphasia, since naming latency can be difficult to measure, especially in speakers with agrammatic aphasia due to concomitant motor speech impairments (Dell et al., 1997; Schwartz, Dell, Martin, Gahl, & Sobel, 2006). If parallel PF effects are reflected in aphasic participants' viewing time data, eyetracking will provide an alternative to naming latency for real-time measurement of lexical retrieval processes in aphasia. Experiment 1 was conducted prior to Experiment 2 in the same group of participants.

Method

Experiment 1: single picture naming

Participants

A total of 43 participants were tested: 13 participants with agrammatic aphasia, 10 participants with anomic aphasia, and 20 age-matched controls. Control participants (11 males, 9 females; age = 60.2 (8.8) years old; education = 15.9 (2.7) years) were recruited from the Chicago community and compensated for their participation. Participants with aphasia were recruited from the Northwestern Aphasia and Neurolinguistics Research Laboratory and Northwestern University Speech, Language and Learning Clinic (agrammatic: 5 females, 8 males; age = 58.6 (12.1) years old; education = 16.9 (2.7) years; post onset of stroke = 7.2 (4.5) years; anomic: 3 females, 7 males; age = 55.6 (6.5) years old; education = 15.9 (2.4) years; post onset of stroke = 3.6 (2.4) years). Controls were matched with the aphasic groups in terms of age, F (2, 40) = .794, p = . 459, and years of education, F (2, 40) = .674, p = . 515. All participants with aphasia were monolingual native speakers of English with aphasia resulting from a left hemisphere CVA, except for one agrammatic participant whose aphasia resulted from a right hemisphere CVA. All control and aphasic participants had normal or corrected-to-normal vision and hearing and had no prior history of developmental speech, language, or learning disorders, psychiatric illness, or neurological disease other than stroke. All participants were tested in the Aphasia and Neurolinguistics Research Laboratory at Northwestern University. The study was approved by the Institutional Review Board at Northwestern University, and all participants provided informed consent.

Participants' performance on the *Western Aphasia Battery-Revised* (WAB-R, Kertesz, 2006) served as the primary measure for aphasic group assignment (see Table 1). Those in the agrammatic group showed impaired production of sentences and disfluent speech with reduced grammatical complexity (Fluency score of 4 or 5) and were classified as either Broca's or Transcortical Motor Aphasia on the WAB-R. Those in the anomic aphasic group showed fluent speech with relatively preserved syntactic structure (Fluency score of 6 or above) and were classified as Anomic Aphasia on the WAB-R.

In order to ensure that the two aphasia groups show language deficit patterns consistent with agrammatic versus anomic aphasia, the Sentence Production Priming Test (SPPT) and Sentence Comprehension Test (SCT) from the *Northwestern Assessment of Verbs and Sentences* (NAVS, Thompson, 2011) and the *Northwestern Assessment of Verb Inflection* (NAVI, Lee & Thompson, experimental version) were administered. For the NAVS, production and comprehension scores were computed separately for canonical (actives, subject wh-questions, subject relatives) and noncanonical (passives, object wh-questions, object relatives) sentences. A 2 x 4 ANOVA revealed a significant main effect of group, F (1, 21) = 6.87, $p < .001$, and subtest, F (3, 63) = 19. 22, $p < .001$, as well as a significant interaction between group and subtest, F (3, 63) = 4.08, $p = .01$. Whereas the agrammatic group showed overall lower performance than the anomic group, the between group difference was reliable for production of noncanonical sentences only, t (18) = 3.08, $p < .006$, in keeping with sentence production and comprehension patterns for agrammatic aphasia reported in the literature (Cho-Reyes & Thompson, 2012; Rochon, Laird, Bose, & Scofield, 2005; Schwartz, Saffran, Fink, Myers, & Martin, 1994). On the NAVI, a 2 (group) x 2 (finiteness) ANOVA revealed higher scores in the anomic than agrammatic group, F (1, 21) = 7.631, $p = .012$. Both groups produced nonfinite forms (infinitive, present progressive) more accurately than finite forms (present singular, present plural, past regular, and past irregular), F (1, 21) = 24. 60, $p < .001$. Although the interaction between group and finiteness reached significance at .10 level, F (1, 21) = 3.67,

Table 1. Language testing scores for agrammatic and anomic participants.

	WAB-R					NAVS				NAVI	
Participants	AQ	Fluency	AC	Rep	Naming	SPPT-C	SPPT-NC	SCT-C	SCT-NC	Nonfinite	Finite
Agrammatic participants											
G1	74.4	4.0	7.9	8.1	8.2	100	60	80	80	65	53
G2	87.6	5.0	10.0	10.0	9.8	100	66	100	100	100	77
G3	81.2	4.0	10.0	8.8	8.8	87	53	93	80	100	95
G4	83.2	5.0	10.0	9.0	9.6	100	93	100	93	85	100
G5	85.4	5.0	10.0	9.5	9.2	100	53	100	93	91	40
G6	77.6	5.0	7.8	9.4	7.6	53	20	53	66	100	38
G7	85.0	5.0	10.0	9.5	9.0	93	86	100	93	100	38
G8	69.9	4.0	9.5	5.0	8.5	100	0	86	80	100	30
G9	82.8	5.0	10.0	8.3	9.1	100	46	93	53	100	88
G10	73.5	5.0	8.6	6.4	7.8	93	60	40	73	100	75
G11	79.3	4.0	9.2	9.0	8.5	100	86	100	73	93	65
G12	80.8	5.0	9.0	8.4	9.0	100	27	87	53	100	0
G13	75.2	5.0	8.0	7.0	8.6	87	0	73	20	95	18
Mean	79.7	4.7	9.2	8.3	8.7	93.3	50.0	85.0	73.6	94.5	55.0
SD	5.3	0.5	0.9	1.4	0.6	13.1	30.8	19.3	21.8	10.1	31.0
Anomic participants											
A1	91.1	9.0	8.4	9.2	9.0	93	87	100	100	95	87.5
A2	88.8	6.0	10.0	9.4	10.0	93	100	100	93	95	47.5
A3	88.4	8.0	9.7	8.4	9.1	87	73	93	87	100	55
A4	90.7	9.0	9.9	7.1	9.4	100	73	87	53	100	97.5
A5	88.4	8.0	9.7	8.4	9.1	100	93	100	87	100	85
A6	88.7	9.0	9.5	9.8	7.1	100	80	93	80	100	95
A7	91.8	9.0	9.4	9.2	9.3	100	80	100	100	100	85
A8	93.3	9.0	10.0	9.0	9.7	93	67	100	87	100	82.5
A9	89.4	9.0	9.3	6.4	10.0	100	80	100	100	100	85
A10	89.9	9.0	8.9	8.1	9.0	100	80	80	80	100	97.5
Mean	90.1	8.5	9.5	8.5	9.2	96.7	81.3	95.3	86.7	99.0	81.8
SD	1.6	1.0	0.5	1.1	0.8	4.7	9.8	7.1	14.1	2.1	17.1

Notes: WAB-R = Western Aphasia Battery-Revised; NAVS = Northwestern Assessment of Verbs and Sentences; NAVI = Northwestern Assessment of Verb Inflection; AQ = Aphasia Quotient; AC = Auditory Comprehension; Rep = Repetition; SPPT-C = Sentence Priming Production Test–Canonical; SPPT–NC = Sentence Priming Production Test–Noncanonical; SCT–C = Sentence Comprehension Test–Canonical; SCT–NC = Sentence Comprehension Test–Noncanonical.

$p = .069$, the agrammatic group, compared to the anomic group, produced significantly fewer correct finite forms (55% vs. 82%; $t\,(21) = 2.\,44$, $p = .024$), but no difference in production of nonfinite forms was found (95% vs. 99%; $t\,(21) = 1.37$, $p = .185$) (Lee, Mack, & Thompson, 2012; Lee, Milman, & Thompson, 2008).

Stimuli

A set of 40 nouns (concrete objects) and 40 verbs (including intransitive and transitive imageable actions) were selected, and black-and-white line drawings were prepared for the noun and verb naming tasks, respectively. The noun stimuli and their pictures were selected from Snodgrass and Vanderwart (1980). Verb stimuli and action pictures were selected from those developed in the Northwestern Aphasia and Neurolinguistics Research Laboratory. Target nouns and verbs were matched for variables that are known to affect naming difficulty, including word length (all stimuli were monosyllabic), log lemma frequency (1.62 for nouns vs. 1.56 for verbs, CELEX, Baayen, Piepenbrock, & van Rijn, 1993), and phonological neighbourhood density (17.13 for nouns vs. 17.63 for verbs).

Procedure

Participants were seated in front of the stimulus presentation computer and they were presented with a single black-and-white line drawing and asked to name it using a single word, using Superlab 4.0 (Cedrus). Noun and verb picture stimuli were presented in separate blocks. Within each block, the order of the trials was randomised and the order of noun and verb naming tasks was counterbalanced across participants.

Data analysis

Production accuracies were computed based on correctly produced target words within 7 seconds for aphasic groups and 2 seconds for controls. Production of articles or fillers (e.g., *a book, um-book*) and synonyms (*fix/repair, weigh/measure, dig/shovell*) were accepted. Incorrect responses were tallied into semantic paraphasias (e.g., *spoon* for *fork, dive* for *swim*), unrelated word substitutions (e.g., *pencil* for *comb; copying* for *poke*), mixed errors (e.g., *coat* for *comb*), formal errors (e.g., *crumb* for *comb, packing* for *patting*), and nonword errors (*nida* for *pinch*). "I don't know" responses and the trials in which aphasic participants could not produce a response within the time limit were considered "no response" errors. "Other" errors included unintelligible responses and production of a sentence response (e.g., *the man is playing* for *dig* and *boy, no, the girl is pinching* for *pinch*).

Results

Results are summarised in Table 2. Given that the response variable was binary, a logit mixed model was used to fit the data where the subjects and items were entered as random effects and the group, word category, and interaction were entered as fixed effects. This model was chosen to account for subject and item variability. The R package *lme*4 and the function *glmer* were used (Bates, Maechler, Bolker, & Walker, 2014). To test main effects and interaction effects, we used the likelihood ratio test method to obtain the χ^2 statistics and corresponding p values. There was a significant effect of group, χ^2 (2) = 45.35, $p < .001$. Both agrammatic and anomic groups performed significantly more poorly than controls, p's < .001, independent t-tests. However, there was no reliable difference between the agrammatic and anomic groups in overall naming performance. There was a significant main effect of word category, indicating overall higher scores for noun versus

Table 2. Participant groups' mean naming accuracies (% correct, with standard deviations) in single picture naming task by word category.

Participants	Control	Agrammatic	Anomic
Noun	99 (1.5)	92 (6.2)	90 (10.6)
Verb	98 (2.9)	73 (13.6)	87 (9.9)
p-Value	n.s.	<.001	n.s

Table 3. Number and proportion (%) of errors produced by type in the single picture naming task.

	Agrammatic participants		Anomic participants	
Error type	Noun	Verb	Noun	Verb
Semantic	16 (46%)	71 (52%)	19 (49%)	25 (52%)
Unrelated	3 (9%)	7 (5%)	4 (10%)	3 (6%)
Mixed	0 (0)	3 (2%)	1 (3%)	2 (4%)
Formal	1 (3%)	7 (5%)	3 (8%)	0 (0%)
Nonword	0 (0)	5 (4%)	4 (10%)	1 (2%)
No response	13 (37%)	23 (17%)	8 (21%)	15 (25%)
Other	2 (6%)	20 (15%)	0 (0%)	5 (10%)
Total	35 (100%)	136 (100%)	39 (100%)	48 (100%)

verb naming, χ^2 (1) = 19.74, $p < .001$. Importantly, there was a significant interaction between word category and group, χ^2 (2) = 20.51, $p < .001$. The agrammatic group produced verbs significantly more poorly than nouns, t (12) = 6. 99, $p < .001$, with all (13/13) participants in this group showing this pattern. However, no reliable difference between noun and verb naming was noted for the anomic or the control group.

Table 3 summarises error types from the aphasic groups. Age-matched control participants produced very few erred responses, mainly consisting of semantically related word substitutions; thus, their error types are not reported. No notable differences were observed in error types between noun and verb naming in the aphasic groups. For both agrammatic and anomic groups, the most frequent error type was production of semantic paraphasias in both noun and verb naming, followed by "no response" errors. Although much less frequent, other whole-word (lexical) errors were also produced, including substitution of unrelated words, both phonologically and semantically related mixed errors, and formal errors. Importantly, very few nonword (sub-lexical) errors were produced by the aphasic participants.

Summary

Compared to controls, our aphasic groups showed impaired naming. Importantly, verbs were more impaired than nouns in the agrammatic group, as predicted; however, no dissociation was shown in the anomic group, different from our prediction. Both groups produced mostly lexical (dominated by semantic) errors; but sub-lexical errors were rare, suggesting underlying lexical selection (versus phonological encoding) deficits.

Experiment 2: phonological priming task

Extending Meyer and van der Muelen (2000), we used an eyetracking auditory priming paradigm during noun and verb naming. For testing each word category, related and unrelated prime conditions were included. In related conditions, auditory prime words were phonologically related to target words, sharing word-initial consonant and vowel phonemes (*belt–bed*), whereas in the unrelated conditions, the prime words were phonologically unrelated to target words (*pot–bed*). Using a within-item design, the same target word was elicited twice—once with a related and once with an unrelated prime word.

Participants

The same aphasic and age-matched control participants from Experiment 1 were tested. In addition, we tested young controls (16 females, 4 males; age M (*SD*) = 21.8 (2.5) years old), undergraduate, or graduate student volunteers from Northwestern University. All young controls had normal or corrected-to-normal hearing and vision without any history of neurological or speech–language disorders. We included young controls, in addition to age-matched controls, because previous phonological priming studies, including Meyer and van der Meulen (2000)'s, examined PF effects for nouns only; the effects of phonological primes on verb naming were not tested.

Stimuli

Using the same target stimuli from Experiment 1, 20 pairs of object pictures and 20 pairs of action pictures were prepared for the noun and verb naming tasks (see the Appendix for stimulus lists, together with corresponding primes). For each pair of pictures, one appeared on the left and one on the right side of the screen. Between the left- and right-sided pictures, a set of linguistic variables were equated (log lemma frequency: 1.62 vs. 1.62 for nouns; 1.38 vs. 1.53 for verbs; phonological neighbourhood density: 17.4 vs.16.9 for nouns; 18.4 vs. 17.0 for verbs, *p*'s > .54, t-tests). For each pair of target nouns and verbs, two prime words were prepared that were either phonologically related or unrelated to the name of the left-sided target picture. All primes (n = 80) were monosyllabic nouns. The primes were matched between the related vs. unrelated conditions for frequency (1. 37 vs. 1.31 for nouns; 1.38 vs. 1.37 for verbs) and phonological neighbourhood (17.7 vs. 18.4 for nouns; 17.3 vs. 18.5 for verbs), *p*'s > .67, t-tests. The spoken word durations of the primes, recorded by a male native speaker of North American English, were also matched between the related and unrelated conditions for both the noun (536 ms vs. 556 ms) and verb naming (544 ms vs. 542 ms), *p*'s >.38.

Apparatus

The stimuli were presented on a 19-inch PC computer, using Superlab 4.0 (Cedrus), and a Dell computer was used for recoding eye and speech data. The phonological primes were presented over two speakers, and participants' naming responses were recorded using Praat software. Eye movements were monitored using a video-based pupil and corneal reflection system, Applied Science Laboratories (ASL) model D6 remote eyetracker. The eyetracker was placed in front of the stimulus presentation computer and controlled by Eyelink system software, which connected the two computers used for stimulus display and eye data recording. Only one eye was monitored. Throughout the experiment, the onset and offset times and spatial coordinates of the participants' fixations were sampled at every 4 ms.

Procedure

Participants were presented with a pair of pictures and asked to name the pictures from left to right, as in Figure 2. In both noun and verb naming tasks, a prime word was presented at the onset of a picture pair (SOA = 0 ms). Participants were instructed to ignore the word that they heard and try to name the pictures as fast as they could.

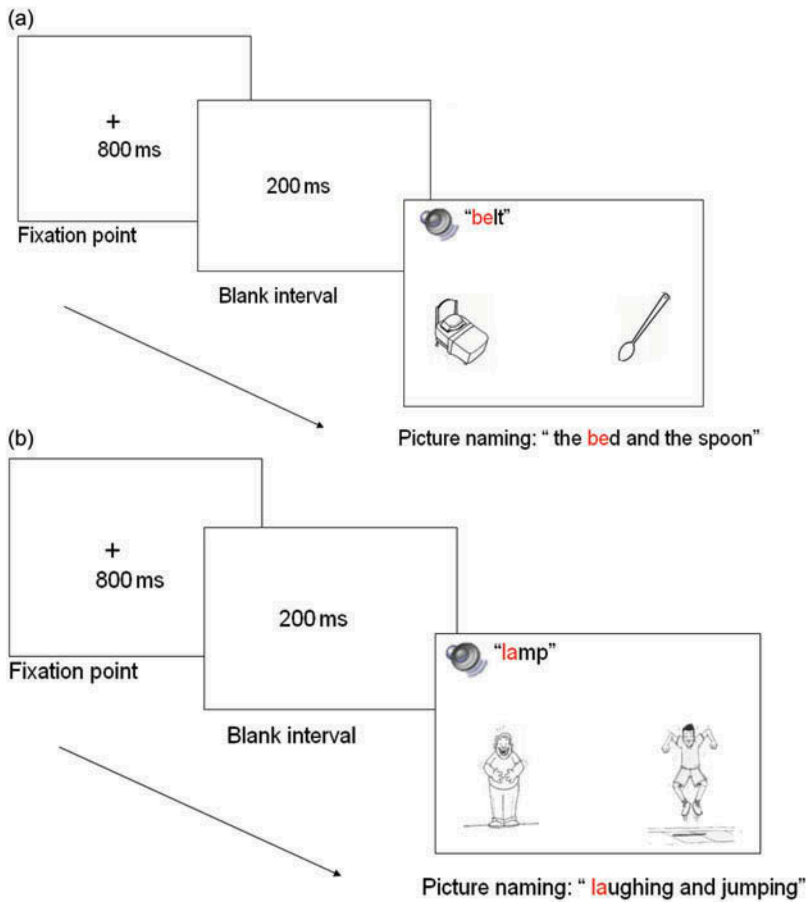

Figure 2. Sample experimental trials for phonological priming during noun (a) and verb naming (b). [To view this figure in colour, please see the online version of this Journal.]

Participants went through a set of 6 practice trials prior to the experimental task. No feedback regarding the naming accuracy was provided.

The noun and verb naming tasks were presented separately, with the order of the tasks counterbalanced across participants. Within each task, the order of trials was randomised across participants. Participants' eyes were calibrated using a nine-point calibration screen, which occurred at the beginning of the task as well as every 10 experimental trials as necessary. During the task, participants' eye movements and speech responses were recorded.

Data analyses

Participants' naming accuracies were computed based on responses produced for the left-sided picture. Omission of an article (*bed* instead of *a/the bed*) was accepted. Following previous studies (Damian & Martin, 1999; Meyer & van der Meulen, 2000), "disfluent" responses were not considered correct responses, including target responses produced following a filler (e.g., *uh bed*) or a prolonged article (e.g., *the—bed*), within-word self-corrections (e.g., *s-no-fork*), and delayed responses (i.e., responses produced after delays of 2000 milliseconds for controls and 7000 milliseconds for participants with aphasia). Naming latencies and viewing times were obtained for correct responses only, with latency measured from the onset of the phonological prime to the production onset of the first consonant of the target noun or verb. Naming latencies were hand-coded by the experimenter and two research assistants, using Praat software (Boersma & Weenink, 2009), and viewing times to the left picture before speech onset were calculated. Areas of the interest (AOIs) were drawn around the target picture within two degrees of the visual margin. Fixations falling within AOIs for each target picture, from the onset of the picture stimulus until naming onset, were summed to derive total viewing times per condition (Meyer & van der Meulen, 2000).

Results

Noun naming. Table 4 summarises noun naming performance for each participant group, including mean naming accuracies, naming latencies, and viewing times for the target picture between the related and unrelated conditions. Two aphasic participants from each group were excluded from viewing time data analyses due to failure to record enough fixation points (greater than 500 fixations). Figure 3 shows the PF effects on noun naming latencies and viewing times computed by the differences between the related and unrelated conditions for each group. For the accuracy data, a logit mixed model was used, as in Experiment 1. For the latency and viewing time data, because the response variable was continuous, linear mixed models were conducted using SPSS. The group, relatedness, and the interaction between the two were entered as fixed effects in the models. To account for variability across participants and items, the model also included random intercepts for each participant and item.

For *noun naming accurac*y data, there was a significant main effect of group, χ^2 (3) = 38.17, $p < .001$. Both agrammatic and anomic groups produced significantly fewer correct responses compared to young and age-matched controls, p's < .001, independent t-tests. All other comparisons were not significant. Neither the effect of relatedness, χ^2 (1) = 2.21, $p = .13$, nor the interaction between relatedness and group, χ^2 (3) = 0.29, $p = .96$, was significant.

For *both noun naming latencies* and *viewing times*, group effects were significant, F (3, 58) = 41.13 for latencies, F (3, 57) = 54.52 for viewing times, p's < .001. Both agrammatic and anomic groups showed significantly longer latencies and viewing times than young and age-matched controls, p's <. 05, independent t-tests. In addition, agrammatic group showed longer naming latencies and viewing times compared to anomic group, p's < .01. Overall, both latencies and viewing times were significantly reduced in the related compared to unrelated priming condition, F (1, 2105) = 20.27; F (1, 1923) = 14.945, p's < .01. Significant interactions between relatedness and group also were found (at the .10 level) for both measures, F (3, 2105) = 2.341, $p = .07$, F (3, 1923) = 2.202, $p = .08$. Paired t-tests revealed significantly reduced naming latencies and viewing times in the related compared to the unrelated condition in young ($p < .01$; $p < .05$), age-matched ($p < .01$; $p < .05$), and anomic group ($p < .05$; $p <$. 01). Importantly, however, these differences were not significant in agrammatic group (p's >.21).

Verb naming. Table 5 and Figure 4 summarise the results from the verb naming task. The same statistical analyses were conducted as in noun naming. For *verb naming accuracy*, there was a significant main effect of group, χ^2 (3) = 45.68, $p < .001$. Both agrammatic and anomic groups produced significantly fewer correct responses

Table 4. Phonological facilitation effects in noun naming for each participant group (with standard errors).

	Naming accuracies (%)			Naming latencies (ms)			Viewing times (ms)		
Participants	Related	Unrelated	*p*-Value	Related	Unrelated	*p*-Value	Related	Unrelated	*p*-Value
Young	96 (1.1)	97 (0.8)	n.s.	751 (35)	791 (36)	**	403 (34)	435 (37)	*
Age-matched	96 (1.2)	96 (1.0)	n.s	788 (34)	817 (33)	**	364 (15)	399 (18)	*
Agrammatic	80 (3.7)	80 (2.2)	n.s.	2157 (206)	2235 (172)	n.s.	1414 (115)	1481 (101)	n.s.
Anomic	74 (3.9)	77 (4.2)	n.s.	1415 (108)	1611 (141)	*	663 (58)	798 (65)	**

Notes: *$p < .05$, **$p < .01$.

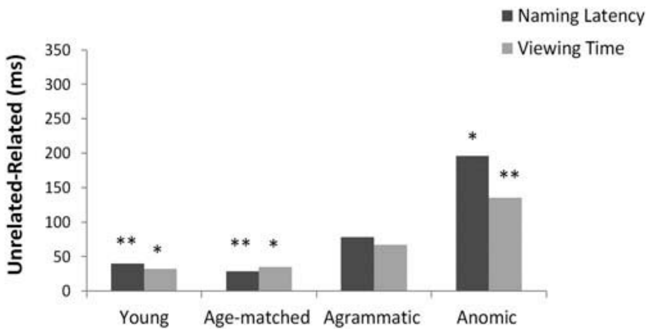

Figure 3. Phonological facilitation effects in noun naming (**$p < .01$, *$p < .05$).

compared to young and age-matched controls, p's < .001. All other comparisons were not significant, p's > .10. Neither the main effect of relatedness, χ^2 (1) = 1.19, p = .27, nor the interaction between relatedness and group was significant, χ^2 (3) = 3.56, p = .31.

For both *verb naming latencies* and *viewing times*, the group effects were significant, F (3, 58) = 32.99 for latencies; F (3, 54) = 18.82 for viewing times, p's < .001. Both agrammatic and anomic groups showed significantly longer latencies, as well as viewing times than young and age-matched controls, p's <. 003. In addition, agrammatic group showed longer naming latencies compared to anomic group, p = .002. Significantly shorter naming latencies and viewing times were shown in the related compared to unrelated prime conditions, overall, F (1, 2070) = 13. 64; F (1, 1828) = 21.18, p's < .001. The interaction between relatedness and group was significant for latencies, F (3, 2069) = 7. 53, p < .001, and reliable at the .10 level for viewing times, F (3, 1828) = 2.09, p = .09. A series of paired t-tests revealed significantly faster naming latencies as well as viewing times in the related compared to the unrelated condition in young (p's < .007), age-matched (p's < .003), and agrammatic group (p's < .006); however, the difference was not significant in anomic group (p's > .11).

Individual analyses. Additional analyses of individual participants' performance were conducted to examine the relation between noun (N) versus verb (V) naming deficits (computed by N-V% correct naming in Experiment 1) and the magnitude of PF for verbs versus nouns (i.e., mean unrelated-related RT per word category in Experiment 2). As mentioned before, all participants with agrammatic aphasia showed greater verb deficits in Experiment 1 (N-V % difference M (*SD*) = 19 (10) %). Variable patterns were noted for participants with anomic aphasia (N-V% difference M (*SD*) = 3 (13)%), with two participants showing greater noun impairments (13–18%), four showing minimal-to-no difference between nouns and verbs (0%–5%), and three showing greater verb impairments (20%). Figure 5 shows the individual participants' PF effects for the agrammatic (top figures) and anomic (bottom figures) groups. For the agrammatic group, all but one (12/13) showed PF (positive bars) for verbs in Experiment 2, as revealed by naming RT and/or viewing time, consistent with the group data. PF for nouns was variable across participants. For participants with anomic aphasia, a consistent relation between word-category naming accuracy and PF was not apparent for either nouns or verbs. However, consistent with the group data, most participants showed PF for nouns, with greater individual variability noted for verbs.

Table 5. Phonological facilitation effects in verb naming for each participant group (with standard errors).

	Naming accuracies (%)			Naming latencies (ms)			Viewing times (ms)		
Participants	Related	Unrelated	*p*-Value	Related	Unrelated	*p*-Value	Related	Unrelated	*p*-Value
Young	96 (1.1)	96 (0.8)	n.s.	796 (30)	877 (34)	**	439 (27)	471(32)	**
Age-matched	90 (1.5)	93 (1.0)	n.s.	846 (28)	896 (29)	***	391 (21)	435 (23)	**
Agrammatic	75 (3.3)	74 (3.1)	n.s	1,921 (185)	2,225 (193)	**	966 (81)	1,099 (94)	**
Anomic	77 (2.7)	74 (3.0)	n.s.	1,618 (144)	1,583 (134)	n.s.	843 (72)	906 (83)	n.s.

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

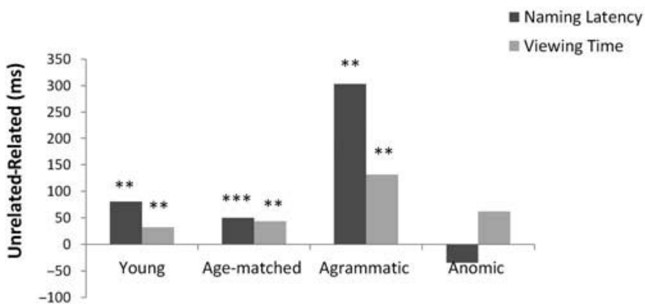

Figure 4. Phonological facilitation effects in verb naming (***$p < .001$, **$p < .01$).

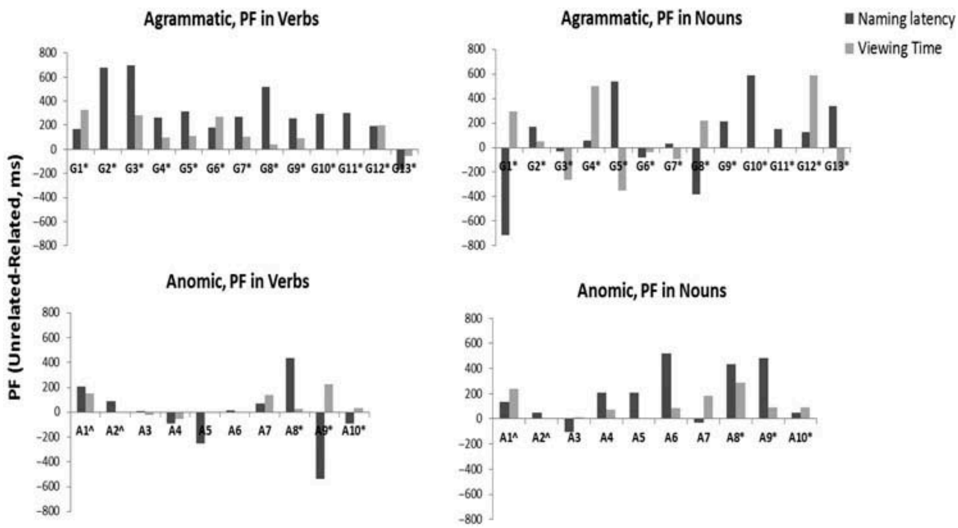

Figure 5. Phonological facilitation (PF) for nouns and verbs for individual participants in Experiment 2 as a function of performance in Experiment 1 (G = Agrammatic participants; A = Anomic participants). Positive bars indicated phonological facilitation and negative bars indicate phonological inhibition. Participants who show greater verb naming deficits in Experiment 1 are indicated by "*" and those who showed greater noun deficits in Experiment 1 are indicated by "^".

Summary

Both young and age-matched controls showed PF effects, reflected by reduced naming latencies and viewing times, regardless of word category. Interestingly, the aphasic groups showed word-category-specific PF. The agrammatic group showed significant PF as reflected in both naming latencies and viewing times for verbs, but not for nouns. Conversely, the anomic group showed significant PF effects for nouns, but not for verbs, although variability was noted for individuals within groups.

Discussion

Previous research has shown that phonologically related, compared to unrelated, primes facilitate noun naming, resulting in faster naming latencies (e.g., Damian & Martin, 1999;

Meyer & Schriefers, 1991; Schriefers et al., 1990), as well as reduced viewing times in young healthy speakers (Meyer & van der Meulen, 2000). Limited research on phonological priming in aphasia suggests that participants with aphasia also show PF during noun naming and lexical decision tasks using various form-related prime types (rhyme, visual, and auditory) (Baum, 1997; Gordon & Baum, 1994; Hashimoto & Thompson, 2009; Milberg et al., 1988; Wilshire et al., 2007; Wilshire & Saffran, 2005). However, whether PF occurs via the sub-lexical or lexical route in aphasia remains unclear. We investigated this question by examining PF during noun and verb naming in agrammatic and anomic aphasia.

The results from Experiment 1 (off-line confrontation naming) revealed impaired lexical selection, with greater impairment for verbs compared to nouns in our agrammatic group. This pattern is consistent with previous studies showing that verb retrieval poses difficulty for individuals with agrammatic aphasia presumably due to more complex semantic-syntactic properties represented in verb lemmas (e.g., Kim & Thompson, 2000; Miceli et al., 1984; Zingeser & Berndt, 1988, 1990). Because word-category specific semantic–syntactic information is only encoded at the lexical level of representation within current models of naming, the noun–verb dissociation seen in our participants with agrammatic aphasia is difficult to be attributed to phonological encoding impairments. That is, a phonological encoding deficit would likely not affect one word category more or less than another. In addition, the dominant semantic errors seen in the agrammatic participants suggest impaired lexical selection, rather than phonological encoding deficits. With regard to the anomic participant group, contrary to our prediction that nouns would be the more impaired word category, they showed equally impaired naming of nouns and verbs. This finding is not surprising, given mixed evidence from previous studies showing that individuals with anomic aphasia may show greater difficulty with nouns than verbs only in certain tasks, such as naming to definitions but not in confrontation naming tasks (Zingerser & Berndt, 1990). However, the naming error analysis showed that the anomic group produced mostly lexical (mainly semantic) errors in the face of rare sub-lexical (phonological, nonword) errors. Considering both discrete and interactive models, dominant lexical-semantic errors indicate a deficit involving lexical selection, rather than impaired phoneme activation (Cuetos et al., 2000; Dell et al., 1997; Gainotti et al., 1986; Hillis et al., 1990; Lambon Ralph et al., 2000; Martin et al., 1996; Rapp & Goldrick, 2000; Schwartz et al., 2006; Wilshire & Saffran, 2005). Therefore, the findings from Experiment 1 suggest that both aphasic groups' naming deficits arise from impaired lexical selection, with this being greater for verbs than nouns in the agrammatic group and indistinguishable with regard to word category for the anomic group.

Turning to the results of Experiment 2, the young and age-matched controls showed significant PF for both nouns and verbs, reflected by decreased naming latencies and viewing times in the related compared to the unrelated prime condition. These findings replicate and extend previous PF effects during noun (object) naming in young healthy speakers (Levelt et al., 1991; Meyer & Schriefers, 1991; Schriefers et al., 1990). Further, they are consistent with Meyer and van der Meulen (2000)'s finding that speakers' viewing times during picture naming reflect lexical access processes (see also Griffin, 2001; Griffin & Bock, 2000; Meyer et al., 1998). PF effects seen in our control participants may be accounted for either sub-lexically, i.e., preactivated phonemes of the prime facilitate target phoneme selection during phonological encoding (Meyer & Schriefers, 1991; Meyer & van der Meulen, 2000; Schriefers et al., 1990) or lexically, whereby the target lexical item receives additional boost over its competitors via feedback from the phonological level to the lexical level (Damian & Martin, 1999; Dell, 1986; Dell et al., 1997; Starreveld & La Heij, 1996). Either way, phonological primes result in enhanced retrieval of the target lexical item.

Interestingly, our aphasic groups showed selective PF effects between nouns and verbs. The agrammatic group showed significant PF only for verbs, the category that they showed greater impairment in off-line naming accuracy in Experiment 1. In contrast, the anomic group showed significant PF only for nouns, although they were equally impaired in off-line naming of nouns and verbs in Experiment 1. Because PF requires successful activation of phonemic representations shared by the prime and target, irrespective of sub-lexical vs. lexical mechanisms, the facilitation effects seen in our aphasic participants suggest that they successfully activated appropriate phonological representations upon hearing auditory primes. This, in turn, indicates that the lack of statistically reliable PF effects in one word category for both groups is difficult to be attributed to impaired processing of phonological prime input or inability to activate shared phonological representations (Baum, 1997; Gordon & Baum, 1994; Milberg et al., 1988).

The results from our agrammatic group clearly support lexically mediated PF. In interactive models, due to cascading and interactive spreading activation within the entire lexical network, phonemes become activated during lexical selection, and this activation can feed back to the lexical level while the target lemma is still being activated (Damian & Martin, 1999; Dell, 1986; Dell et al., 1997; Schwartz et al., 2006; others). Through this feedback mechanism, the target lemma that shares phonemic representations with the phonological prime gains additive activation, resulting in lexically mediated PF. When lexical selection is weakened or not strong enough to distinguish the target from its competitors, phonemes shared by the phonological prime and target strengthen activation of the target lemma over its competitors, which do not share phonemes with the prime. When word-category naming impairments exist, it follows that this boost from primes would be greater for the lexical category (verbs, in this case) in which lemma selection is most compromised. Given that our agrammatic group was more impaired in producing verbs compared to nouns, the greater PF effect for verbs compared to nouns is in line with this interpretation, suggesting that our agrammatic speakers used preactivated phonological representations to compensate for compromised lexical selection.

The anomic group showed a different pattern—significant PF for nouns but not for verbs, and this pattern was seen for most individuals within the group. However, based on our findings from Experiment 1, showing variable word class naming deficit patterns in the anomic participants, it is difficult to clearly locate the source of PF for the anomic group. One possible account is that performance on our off-line confrontation naming test did not adequately capture the deficit patterns of our anomic participants and that lexical selection processes for nouns were, indeed, more impaired than for verbs (e.g., greater noise or greater competition between lemmas) (also see Wilshire et al., 2007 for description of an anomic patient, NP, who showed delayed semantic activation process only in a priming task, but not in an off-line comprehension). In this case, preactivated phonemes from related primes might have served to facilitate lexical selection of nouns to a greater extent compared to verbs in general. However, this explanation is preliminary and awaits further investigation. Nonetheless, the selective PF effect for nouns but not for verbs in our anomic group clearly suggests the presence of a feedback mechanism from the phonological to the lexical level, consistent with interactive, but not with the discrete models of naming.

The selective PF effects noted here suggest that PF is not strictly localised at the level of phonological encoding, but rather that it may be lexically mediated, at least in individuals with aphasia. These findings are in keeping with previous studies showing that phonological primes are capable of influencing lexical selection process in individuals with aphasia (Wilshire et al., 2007; Wilshire & Saffran, 2005). Further, our findings suggest that such primes may facilitate improved naming for difficult-to-name items, boosting lexical selection process. Phonological priming may, therefore, be a useful strategy for improving lexical retrieval deficits in individuals with aphasia.

The lack of reliable PF effects in the "less impaired" words in our aphasic participants may be due to increased phonological competition. While phonological primes in general facilitate naming, within interactive models, phonological competition can sometimes occur when processing the target causes reactivation of the phonemes of the prime during phoneme selection, causing a delay in reaction time (Columbo, 1986; Lupker & Columbo, 1994; O'Seagdha & Marin, 2000). This is particularly so when target items are accessed more easily or faster (e.g., high frequency words), increasing the probability of reactivating the prime's residual activation (Columbo, 1986; Lupker & Columbo, 1994). This competition is easily resolved in a timely manner in controls, with no influence on PF (O'Seagdha & Marin, 2000). However, the aphasic groups might have experienced greater difficulty resolving this competition, resulting in reduced PF effects when the competition is strong. When lexical selection is weakened or slowed (i.e., verbs for agrammatic and possibly nouns for anomic group), the probability of the auditorily presented prime to be reactivated decreases because the prime's residual activation is likely to decay by the time lexical selection is completed. As a result, aphasic participants do not experience as much phonological competition, allowing facilitatory processes to proceed normally.

The last question we examined in this study was whether aphasic participants' viewing times would be a sensitive measure of PF effects, in addition to the conventional measure of naming latencies. Results showed that, indeed, when priming-induced differences in naming latencies were significant, our agrammatic and anomic groups showed significant differences in viewing times. This finding suggests that measuring speakers' viewing times is informative in studies examining the time course of lexical access in individuals with aphasia, particularly those whose naming latencies might be difficult to obtain due to frequently co-occurring motor speech disturbances (Dell et al., 1997; Schwartz et al., 2006). These are novel findings indicating that monitoring eye gaze during controlled naming tasks may overcome this methodological limitation and can provide another sensitive measure for investigating on-line lexical access (see also Odekar, Hallowell, Kruse, Moates, & Lee, 2009; for semantic facilitation effects on eye movement patterns during semantic association tasks in healthy young adults and Lee & Thomson, 2011a, 2011b; Lee, Yoshida, & Thompson, accepted; for using eye movements for studying online processes of sentence production in agrammatic aphasia).

We note two important issues that deserve further investigation. First, based on analysis of individual participants' naming deficits and PF patterns (Figure 5), our findings cannot be generalised to indicate that different degrees of impaired naming can predict the magnitude of PF for individuals with aphasia. Notably, however, all but one agrammatic participants and most of the anomic participants showed a pattern confirming our group finding that phonological priming boosted lexical selection of verbs for agrammatic and nouns for anomic groups. Given that we tested a relatively small number of participants with aphasia and used accuracy only to measure naming deficit patterns, further research is needed to map the relation between PF and individual variability in lexical selection deficits. Second, we want to be clear that the present research does not obligate word-category (e.g., nouns, verbs) to be a necessary part of the mechanisms of PF. Study of these two categories, however, is particularly informative because syntactic category information is encoded at the lexical level within the current theories of lexical processing and because the well-established noun and verb dissociation in agrammatic aphasia allows us to test the predictions associated with lexically mediated vs. sub-lexical PF. Thus, as pointed out by a reviewer of this manuscript for publication, it is plausible to assume that the lexically mediated PF effect would be strongest for more impaired words in general, regardless of the word's syntactic category. To address this question directly, how PF interacts with other variables that are known to affect lexical selection such as frequency and length (which were controlled between nouns and verbs in our study) as well as different syntactic complexity within a word category (e.g., verbs with different argument structure entries) should be examined.

In conclusion, the current study, examining PF in individuals with agrammatic and anomic aphasia, showed differential impairments in lexical selection of nouns and verbs in the two groups in an off-line confrontation naming task. Greater naming deficits for verbs than for nouns were found for the agrammatic group and equal impairments for nouns and verbs was found for the anomic group. Both groups also showed dominant semantic errors, indicating impaired lexical selection processes. The eyetracking auditory phonological priming experiment further showed that although young and age-matched controls evince PF for both nouns and verbs, the aphasic groups showed word category specific PF effects. The agrammatic group showed significant PF when naming verbs, but not nouns, indicated by reduced naming latencies as well as viewing times. Conversely, the anomic group showed facilitation for nouns but not for verbs. These findings suggest that phonological primes facilitated impaired lexical selection via feedback activation from the phonological to the lexical level in keeping with interactive models of lexical access (Damian & Martin, 1999; Dell, 1986; Dell et al., 1997; Wilshire & Saffran, 2005), resulting in interaction between PF and deficit patterns in lexical selection in our aphasic groups.

Acknowledgement

The authors thank Julia Schuchard, Monique King, Drs. Aaron Meyer and Soojin Cho-Reyes for their assistance with data collection and analyses and the individuals with aphasia for their participation.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was supported by NIH R01-DC01948 (C.K. Thompson).

References

Baayen, R. H., Piepenbrock, R., & van Rijn, H. (1993). The CELEX lexical database [CD-ROM]. In *Linguistic Data Consortium*. Philadelphia: University of Pennsylvania.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-7. Retrieved from http://CRAN.R-project.org/package=lme4

Bates, E., Chen, S., Tzeng, O., Li, P., & Opie, M. (1991). The noun-verb problem in Chinese aphasia. *Brain and Language*, *41*, 203–233. doi:10.1016/0093-934X(91)90153-R

Baum, S. R. (1997). Phonological, semantic, and mediated priming in aphasia. *Brain and Language*, *60*, 347–359. doi:10.1006/brln.1997.1829

Berndt, R. S., Haendiges, A. N., Mitchum, C. C., & Sandson, J. (1997b). Verb retrieval in aphasia. 2. Relationship to sentence processing. *Brain and Language*, *56*, 107–137. doi:10.1006/brln.1997.1728

Berndt, R. S., Mitchum, C. C., Haendiges, A. N., & Sandson, J. (1997a). Verb retrieval in aphasia 1. Characterizing single word impairments. *Brain and Language*, *56*, 68–106. doi:10.1006/brln.1997.1727

Bock, K., & Levelt, W. J. M. (1994). Language production: Grammatical encoding. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics* (pp. 945–984). San Diego, CA: Academic Press.

Boersma, P., & Weenink, D. (2009). Praat: Doing phonetics by computer [computer program]. Retrieved from www.praat.org

Butterworth, B. (1980). Some constraints on models of language production. In B. Butterworth (Ed.), *Language production, Vol. 1, Speech and talk*. London: Academic Press.

Caramazza, A., & Hillis, A. E. (1990). Where do semantic errors come from? *Cortex*, *26*, 95–122. doi:10.1016/S0010-9452(13)80077-9

Caramazza, A., Miceli, G., & Villa, G. (1986). The role of the (output) phonological buffer in reading, writing, and repetition. *Cognitive Neuropsychology*, *3*, 37–76. doi:10.1080/02643298608252669

Caramazza, A., Papagno, C., & Ruml, W. (2000). The selective impairment of phonological processing in speech production. *Brain and Language*, *75*, 428–450. doi:10.1006/brln.2000.2379

Chen, S., & Bates, E. (1998). The dissociation between nouns and verbs in Broca's and Wernicke's aphasia: Findings from Chinese. *Aphasiology*, *12*, 5–36. doi:10.1080/02687039808249441

Cho-Reyes, S., & Thompson, C. K. (2012). Verb and sentence production and comprehension in aphasia: Northwestern Assessment of Verbs and Sentences (NAVS). *Aphasiology*, *26*, 1250–1277. doi:10.1080/02687038.2012.693584

Columbo, L. (1986). Activation and inhibition with orthographically similar words. *Journal of Experimental Psychology: Human Perception and Performance*, *12*, 226–234.

Cuetos, F., Aguado, G., & Caramazza, A. (2000). Dissociation of semantic and phonological errors in naming. *Brain and Language*, *75*, 451–460. doi:10.1006/brln.2000.2383

Damian, M. F., & Martin, R. C. (1999). Semantic and phonological codes interact in single word production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 345–361.

Dell, G. S. (1986). A spreading activation theory of retrieval in sentence production. *Psychological Review*, *93*, 283–321. doi:10.1037/0033-295X.93.3.283

Dell, G. S., & O'Seaghdha, P. G. (1992). Stages of lexical access in language production. *Cognition*, *42*, 287–314. doi:10.1016/0010-0277(92)90046-K

Dell, G. S., & Reich, P. A. (1981). Stages in sentence production: An analysis of speech error data. *Journal of Verbal Learning and Verbal Behavior*, *20*, 611–629. doi:10.1016/S0022-5371(81)90202-4

Dell, G. S., Schwartz, M. F., Martin, N., Saffran, E. M., & Gagnon, D. A. (1997). Lexical access in aphasic and nonaphasic speakers. *Psychological Review*, *104*, 801–838. doi:10.1037/0033-295X.104.4.801

Foygel, D., & Dell, G. S. (2000). Models of impaired lexical access in speech production. *Journal of Memory and Language*, *43*, 182–216. doi:10.1006/jmla.2000.2716

Gainotti, G., Silveri, M., Villa, G., & Miceli, G. (1986). Anomia with and without lexical comprehension disorders. *Brain and Language*, *29*, 18–33. doi:10.1016/0093-934X(86)90031-3

Gordon, J. K., & Baum, S. R. (1994). Rhyme priming in aphasia: The role of phonology in lexical access. *Brain and Language*, *47*, 661–683. doi:10.1006/brln.1994.1062

Griffin, Z. M. (2001). Gaze durations during speech reflect word selection and phonological encoding. *Cognition*, *82*, B1–B14. doi:10.1016/S0010-0277(01)00138-X

Griffin, Z. M., & Bock, K. (2000). What the eyes say about speaking. *Psychological Science*, *11*, 274–279. doi:10.1111/1467-9280.00255

Hashimoto, N., & Thompson, C. K. (2009). The use of the picture-word interference paradigm to examine naming abilities in aphasic individuals. *Apha Siology*, *24*, 580–611.

Hillis, A. E., Boatman, D., Hart, J., & Gordon, B. (1999). Making sense out of jargon: A neurolinguistic and computational account of jargon aphasia. *Neurology*, *53*, 1813–1813. doi:10.1212/WNL.53.8.1813

Hillis, A. E., Rapp, B., Romani, C., & Caramazza, A. (1990). Selective impairment of semantics in lexical processing. *Cognitive Neuropsychology*, *7*, 191–243. doi:10.1080/02643299008253442

Hyun, J. 2003. Retrieval of nouns and verbs in Broca's and Wernicke's aphasia. *Korean Journal of Speech-Language Pathology*, [in Korean] *8*, 171–187.

Jonkers, R., & Bastiaanse, R. (1998). How selective are selective word class deficits? Two case studies of action and object naming. *Aphasiology*, *12*, 245–256. doi:10.1080/02687039808249453

Kay, J., & Ellis, A. (1987). A cognitive neuropsychological case study of anomia. *Brain*, *110*, 613–629. doi:10.1093/brain/110.3.613

Kempen, G., & Hujibers, P. (1983). The lexicalization process in sentence production and naming: Indirect election of words. *Cognition*, *14*, 185–209. doi:10.1016/0010-0277(83)90029-X

Kertesz, A. (2006). *Western Aphasia Battery – Revised*. San Antonio, TX: PsychCorp.

Kim, M., & Thompson, C. K. (2000). Patterns of comprehension and production of nouns and verbs in agrammatism: Implications for lexical organization. *Brain and Language*, *74*, 1–25. doi:10.1006/brln.2000.2315

Kohn, S. E., Lorch, P., & Pearson, D. M. (1989). Verb finding in aphasia. *Cortex*, *25*, 57–69. doi:10.1016/S0010-9452(89)80006-1

Laine, M., & Martin, N. (1996). Lexical retrieval deficit in picture naming: Implications for word production models. *Brain and Language*, *53*, 283–314. doi:10.1006/brln.1996.0050

Lambon Ralph, M. A., Sage, K., & Roberts, J. (2000). Classical anomia: A neuropsychological perspective on speech production. *Neuropsychologia*, *38*, 186–202. doi:10.1016/S0028-3932(99)00056-1

Lee, J., Mack, J., & Thompson, C. K. (2012). Verbal morphology in agrammatic and anomic aphasia: Comparison of structured vs. narrative elicitation tasks. Poster presented at *Clinical Aphasiology Conference*, Lake Tahoe, CA.

Lee, J., Milman, L. H., & Thompson, C. K. (2008). Functional category production in English agrammatism. *Aphasiology*, *22*, 893–905. doi:10.1080/02687030701865670

Lee, J., & Thompson, C. K. (2011a). Real-time production of arguments and adjuncts in normal and agrammatic speakers. *Language and Cognitive Processes*, *26*, 985–1021. doi:10.1080/01690965.2010.496237

Lee, J., & Thompson, C. K. (2011b). Real-time production of unergative and unaccusative sentences in normal and agrammatic speakers: An eyetracking study. *Aphasiology*, *25*, 813–825. doi:10.1080/02687038.2010.542563

Lee, J., & Thompson, C. K. (experimental version). Northwestern Assessment of Verb Inflection.

Lee, J., Yoshida, M., & Thompson, C. K. (accepted). Grammatical planning units during real-time sentence production in agrammatic aphasia and healthy speakers. *Journal of Speech, Language, and Hearing Research*.

Levelt, W. J. M. (1989). *Speaking: From Intention to articulation*. Cambridge, MA: MIT press.

Levelt, W. J. M. (2001). Spoken word production: A theory of lexical access. *Proceedings of the National Academy of Sciences*, *98*, 13464–13471. doi:10.1073/pnas.231459498

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, *22*, 1–75. doi:10.1017/S0140525X99001776

Levelt, W. J. M., Schriefers, H., Vorberb, D., Meyer, A. S., Pechmann, T., & Havinga, J. (1991). The time course of lexical access in speech production: A study of picture naming. *Psychological Review*, *98*, 122–142. doi:10.1037/0033-295X.98.1.122

Lupker, S. J., & Columbo, L. (1994). Inhibitory effects in form priming: Evaluating a phonological competition explanation. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 437–451.

Luzzatti, C., & Chierchia, G. (2002). On the nature of selective deficits involving nouns and verbs. *Revista Di Linguistica*, *14.1*, 43–71.

Mack, J. E., Cho-Reyes, S., Kloet, J. D., Weintraub, S., Mesulam, -M.-M., & Thompson, C. K. (2013). Phonological facilitation of object naming in agrammatic and logopenic primary progressive aphasia (PPA). *Cognitive Neuropsychology*, *30*, 172–193. doi:10.1080/02643294.2013.835717

Martin, N., Gagnon, D. A., Schwartz, M. F., Dell, G. S., & Saffran, E. M. (1996). Phonological facilitation of semantic errors in normal and aphasic speakers. *Language and Cognitive Processes*, *11*, 257–282. doi:10.1080/016909696387187

McCarthy, R., & Warrington, E. K. (1985). Category specificity in an agrammatic patient: The relative impairment of verb retrieval and comprehension. *Neuropsychologia*, *23*, 709–727. doi:10.1016/0028-3932(85)90079-X
Meyer, A. S., & Schriefers, H. (1991). Phonological facilitation in picture-word interference experiments: Effect of stimulus onset asynchrony and types of interfering stimuli. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 1146–1160.
Meyer, A. S., Sleiderink, A. M., & Levelt, W. J. M. (1998). Viewing and naming objects: Eye movements during noun phrase production. *Cognition*, *66*, B25–B33. doi:10.1016/S0010-0277(98)00009-2
Meyer, A. S., & van der Meulen, F. F. (2000). Phonological priming effects on speech onset latencies and viewing times in object naming. *Psychonomic Bulletin & Review*, *7*, 314–319. doi:10.3758/BF03212987
Miceli, G., Silveri, M. C., Villa, G., & Caramazza, A. (1984). On the basis for the agrammatic's difficulty in producing main verbs. *Cortex*, *20*, 207–220. doi:10.1016/S0010-9452(84)80038-6
Milberg, W., Blumstein, S., & Dworetzky, B. (1988). Phonological processing and lexical access in aphasia. *Brain and Language*, *34*, 279–293. doi:10.1016/0093-934X(88)90139-3
Myerson, R., & Goodglass, H. (1972). Transformational grammar of three agrammatic patients. *Language and Speech*, *15*, 40–50.
O'Seagdha, P. G., & Marin, J. W. (2000). Phonological competition and cooperation in form-related priming: Sequential and nonsequential processes in word production. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 57–73.
Odekar, A., Hallowell, B., Kruse, H., Moates, D., & Lee, C.-Y. (2009). Validity of eye movement methods and indices for capturing semantic (associative) priming effects. *Journal of Speech, Language, and Hearing Sciences*, *52*, 31–48.
Rapp, B., & Goldrick, M. (2000). Discreteness and interactivity in spoken word production. *Psychological Review*, *107*, 460–499. doi:10.1037/0033-295X.107.3.460
Rochon, E., Laird, L., Bose, A., & Scofield, J. (2005). Mapping therapy for sentence production impairments in nonfluent aphasia. *Neuropsychological Rehabilitation*, *15*, 1–36. doi:10.1080/09602010343000327
Roelofs, A., Meyer, A. S., & Levelt, W. J. M. (1996). Interaction between semantic and orthographic factors in conceptually driven naming: Comment of Starreveld and LaHeij (1995). *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 246–251.
Saffran, E., Schwartz, M., & Marin, O. S. M. (1980). Evidence from aphasia: Isolating the components of a production model. In B. Butterworth (Ed.), *Language production Vol. 1: Speech and Talk*. New York: Academic Press.
Schriefers, H., Meyer, A., & Levelt, W. J. M. (1990). Exploring the time course of lexical access in language production: Picture-word interference studies. *Journal of Memory and Language*, *29*, 86–102. doi:10.1016/0749-596X(90)90011-N
Schwartz, M. F., Dell, G. S., Martin, N., Gahl, S., & Sobel, P. (2006). A case-series test of the interactive two-step model of lexical access: Evidence from picture naming. *Journal of Memory and Language*, *54*, 228–264. doi:10.1016/j.jml.2005.10.001
Schwartz, M. F., Saffran, E. M., Fink, R. B., Myers, J. L., & Martin, N. (1994). Mapping therapy: A treatment programme for agrammatism. *Aphasiology*, *8*, 19–54. doi:10.1080/02687039408248639
Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory*, *6*, 174–215.
Starreveld, P. A. (2000). On the interpretation of onsets of auditory context effects in word production. *Journal of Memory and Language*, *42*, 497–525. doi:10.1006/jmla.1999.2693
Starreveld, P. A., & La Heij, W. (1996). Time-course analyses of semantic and orthographic context effects in picture naming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 896–918.
Stemberger, J. P. (1985). An interactive activation model of language production. In A. Ellis (Ed.), *Progress in the psychology of language* (pp. 143–186). London: Lawrence Erlbaum and Associates.
Thompson, C. K. (2011). *Northwestern Assessment of Verbs and Sentences*. Evanston, IL: Northwestern University. Retrieved from http://flintbox.com/public/project/9299/

Thompson, C. K., Shapiro, L. P., Tait, M., Jacobs, B., Schneider, S. L., & Ballard, K. (1995). A system for the linguistic analysis of agrammatic language production. *Brain and Language*, *51*, 124–129.

Williams, S. E., & Canter, G. J. (1987). Action-naming performance in four syndromes of aphasia. *Brain and Language*, *32*, 124–136. doi:10.1016/0093-934X(87)90120-9

Wilshire, C. E., Keall, L. M., Stuart, E. J., & O'Donnell, D. J. (2007). Exploring the dynamics of aphasic word production using the picture-word interference task: A case study. *Neuropsychologia*, *45*, 939–953. doi:10.1016/j.neuropsychologia.2006.08.026

Wilshire, C. E., & McCarthy, R. A. (1996). Experimental investigations of an impairment in phonological encoding. *Cognitive Neuropsychology*, *13*, 1059–1098. doi:10.1080/026432996381782

Wilshire, C. E., & Saffran, E. M. (2005). Contrasting effects of phonological priming in aphasic word production. *Cognition*, *95*, 31–71. doi:10.1016/j.cognition.2004.02.004

Zingeser, L. B., & Berndt, R. S. (1988). Grammatical class and context effects in a case of pure anomia: Implications for models of language production. *Cognitive Neuropsychology*, *5*, 473–516. doi:10.1080/02643298808253270

Zingeser, L. B., & Berndt, R. S. (1990). Retrieval of nouns and verbs in agrammatism and anomia. *Brain and Language*, *39*, 14–32. doi:10.1016/0093-934X(90)90002-X

Appendix. Stimuli for noun and verb naming with their related and unrelated primes

Noun naming			
Noun1	Noun2	Related Prime	Unrelated prime
clock	skirt	clot	grape
ring	key	risk	jet
door	book	dope	foil
glove	spoon	glut	jade
hat	fork	hand	bull
bed	shirt	belt	jaw
pen	boot	pest	log
knife	wheel	night	house
desk	shoe	den	cart
nail	bat	name	leg
lamp	bell	lag	sun
church	car	chunk	frog
lock	bench	lot	road
cake	box	cane	gut
broom	flag	brute	harp
truck	dress	trunk	pie
train	watch	trait	flu
drum	sock	drug	wire
comb	kite	coal	tip
cup	fence	curse	rat
Verb naming			
Verb1	Verb2	Related Prime	Unrelated prime
run	sleep	rug	clip
bark	pray	bomb	top
dive	bowl	dime	bug
sit	cry	sink	net
laugh	walk	land	cow
skate	yawn	scale	egg
jump	scream	junk	crook
swim	cough	swing	monk
fish	crawl	fist	sky
wink	howl	wind	cat
bite	watch	bike	jug
cut	squeeze	cult	bump
kick	pat	king	note
lift	poke	limb	bus
hit	pull	hip	soap
hug	crown	hut	lung
dig	stir	din	hint
chase	kiss	chain	cream
fix	wrap	fig	gum
pinch	weigh	pig	mud