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

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Abstract

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 and 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.

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

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phonological primes facilitate lexical selection via feedback activation, resulting in greater PF for more difficult (i.e., verbs in agrammatic and possibly nouns in anomie 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 & Huijbers, 1983; 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, Schriefers, Vorberg, Meyer, Pechmen, & Havinga, 1991; Levelt, Roelofs, & Meyer, 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 & Reich, 1981; Dell & O'Seaghdha, 1992; 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 Muelen, 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'Seaghdaha, 1992; Roelofs et al., 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.

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 non-overlapping 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., 0ms) 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'Seaghdha & 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 characterize 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: 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 et al., 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 et al., 1994; Myerson & Goodglass, 1972; Thompson et al., 1995; Saffran, Schwartz, & Martin, 1980; Zingerser & 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 et al., 1997a, 1997b; Jonkers & Bastiaanse, 1998; Kohn et al., 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, Cho-Reyes, Kloet 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, IG, whose profile was consistent with a lexical selection deficit, benefited from begin-related primes only. Conversely, GL 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, NP, who showed a semantic facilitation effect at SOA 0ms (prime presented simultaneously with the target) in an auditory picture-word task due to his significantly delayed semantic activation. NP also showed PF with phonologically related words presented at SOA 0ms, 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 hypothesized 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, Chen, Tzeng, Li, & Opie, 1991; Kim & Thompson, 2000; Luzzatti & Chierchia, 2002; McCarthy & Warrington, 1985; Miceli et al., 1994; Zingesser & 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 et al., 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) yrs old; education = 15.9 (2.7) yrs) 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) yrs old; education = 16.9 (2.7) yrs; post onset of stroke = 7.2 (4.5) yrs; anomic: 3 females, 7 males; age = 55.6 (6.5) yrs old; education = 15.9 (2.4) yrs; post onset of stroke = 3.6 (2.4) yrs). 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 impairments, 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 and 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 2×4 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 non-canonical sentences only, $t(18) = 3.08, p < .006$, in keeping with sentence production and comprehension patterns for agrammatic aphasia reported in the literature (Cho & Thompson, 2012; Rochon, Laird, Bose, & Scofield, 2005; Schwartz, Saffran, Fink, Myers, & Martin, 1994). On the NAVI, a $2(\text{group}) \times 2(\text{finiteness})$ 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, $F(1, 21) = 3.67, p = .069$, 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, Milman, & Thompson, 2008; Lee, Mack, & Thompson, 2012).

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 et al., 1993), and phonological neighborhood 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 randomized 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, digging/shoveling*) 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 non-word 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 summarized 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 *lme4* 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, $\chi^2(2) = 45.35, p < .001$. 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 verb naming, $\chi^2(1) = 19.74, p < .001$. Importantly, there was a significant interaction between word category and group, $\chi^2(2) = 20.51, p < .001$. 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 summarizes 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 non-word (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 condition 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) yrs 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 Appendix 1 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 neighborhood 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 neighborhood (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 (544ms 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. 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 randomized 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 (Meyer & van der Meulen, 2000; Damian & Martin, 1999), '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 millisecond for controls and 7,000 millisecond 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 summarizes 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 accuracy* data, there was a significant main effect of group, $\chi^2(3) = 38.17$, $p < .001$. 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, $\chi^2(1) = 2.21$, $p = .13$, nor the interaction between relatedness and group, $\chi^2(3) = 0.29$, $p = .96$, 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 summarize 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, $\chi^2(3) = 45.68$, $p < .001$. Both agrammatic and anomic groups produced significantly fewer correct responses 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, $\chi^2(1) = 1.19$, $p = .27$, nor the interaction between relatedness and group was significant, $\chi^2(3) = 3.56$, $p = .31$.

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 phonological facilitation (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.

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 phonological facilitation 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 & Saffran, 2005; Wilshire et al., 2007). However, whether phonological facilitation occurs via the sub-lexical or lexical route in aphasia remains unclear. We investigated this question by examining phonological facilitation 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, Silveri, Villa, & Caramazza, 1984; Zingesser & 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, non-word) errors. Considering both discrete and interactive models, dominant lexical-semantic errors indicate a deficit involving lexical selection, rather than impaired phoneme activation (Cuetos, Aguado, & Caramazza, 2000; Dell et al., 1997; Gainotti et al., 1986; Hillis, Rapp, Romani, & Caramazza, 1990; Lambon Ralph, Sage, & Roberts, 2000; Martin et al., 1997; 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 phonological facilitation 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 phonological facilitation effects during noun (object) naming in young healthy speakers (Levelt et al., 1991; Schriefers et al., 1990; Meyer & Schriefers, 1991). 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). Phonological facilitation effects seen in our control participants may be accounted for either sub-lexically, i.e., pre-activated 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 & LaHeij, 1996). Either way, phonological primes result in enhanced retrieval of the target lexical item.

Interestingly, our aphasic groups showed selective phonological facilitation effects between nouns and verbs. The agrammatic group showed significant phonological facilitation 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 phonological facilitation only for nouns, although they were equally impaired in off-line naming of nouns and verbs in Experiment 1. Because phonological facilitation 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 phonological facilitation 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 phonological facilitation. 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 and others). Through this feedback mechanism, the target lemma that shares phonemic representations with the phonological prime gains additive activation, resulting in lexically-mediated phonological facilitation. 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 phonological facilitation effect for verbs compared to nouns is in line with this interpretation, suggesting that our agrammatic speakers used pre-activated phonological representations to compensate for compromised lexical selection.

The anomic group showed a different pattern – significant phonological facilitation 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 phonological facilitation 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, pre-activated 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 phonological facilitation 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 phonological facilitation effects noted here suggest that phonological facilitation is not strictly localized 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 & Saffran, 2005; Wilshire et al., 2007). 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 phonological facilitation 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; Dell, 2005; Lupker and Columbo, 1994; O'Seaghdha & 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 phonological facilitation (O'Seaghdha & 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 phonological facilitation 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 online lexical access (see also Odekar, Hallowell, Kruse et al., 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, submitted for using eye movements for studying on-line 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 phonological facilitation patterns (Figure 5), our findings cannot be generalized to indicate that different degrees of impaired naming can predict the magnitude of phonological facilitation 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 phonological facilitation and individual variability in lexical selection deficits. Secondly, 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 phonological facilitation. 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 phonological facilitation. Thus, as pointed out by a reviewer of this manuscript for publication, it is plausible to assume that the lexically-mediated phonological facilitation effect would be strongest for more impaired words in general, regardless of the word's syntactic category. To address this question directly, how phonological facilitation 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 phonological facilitation 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 phonological facilitation for both nouns and verbs, the aphasic groups showed word category specific phonological facilitation effects. The agrammatic group showed significant phonological facilitation 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 (Damain & Martin, 1999; Dell, 1986; Dell et al., 1997, Wilshire & Saffran, 2005), resulting in interaction between phonological facilitation and deficit patterns in lexical selection in our aphasic groups.

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Appendix 1. 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

Verb naming

Verb1	Verb2	Related Prime	Unrelated prime
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

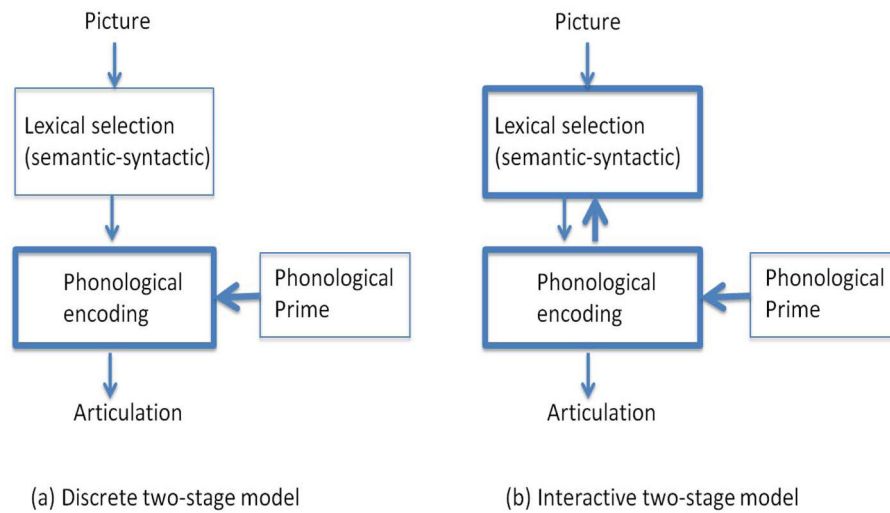


Figure 1.

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.

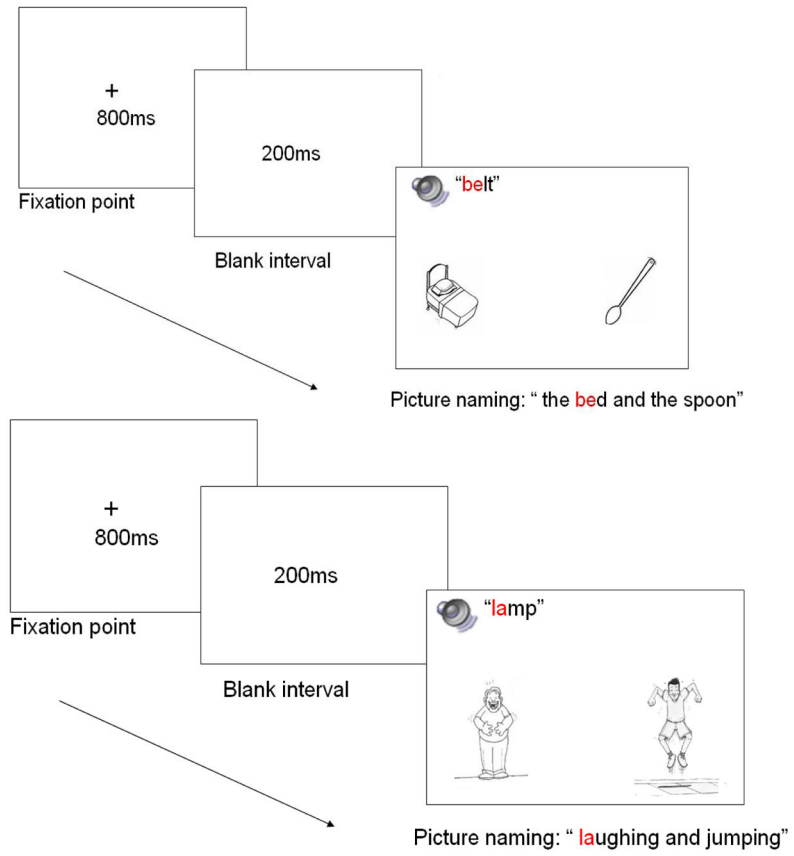


Figure 2. Sample experimental trials for phonological priming during noun (a) and verb naming (b)

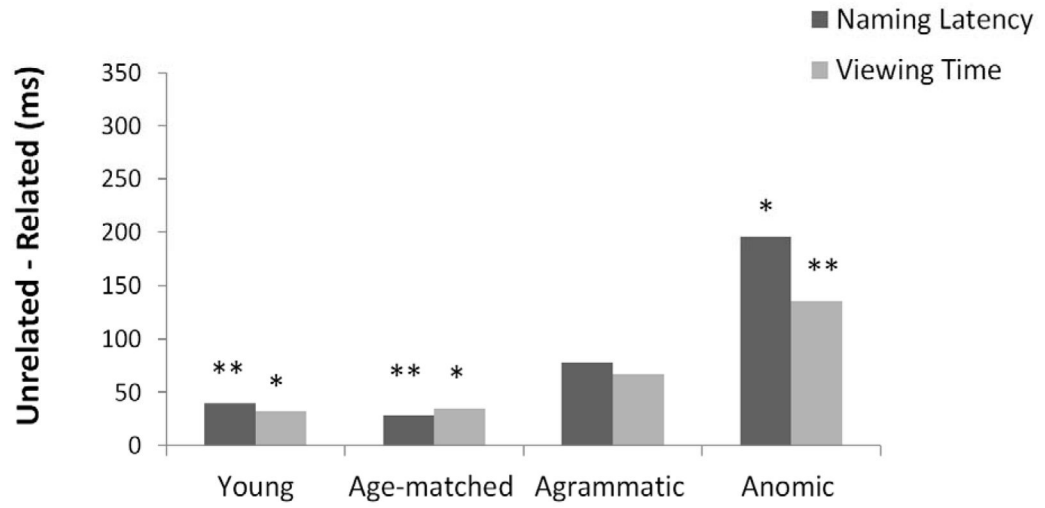


Figure 3. Phonological facilitation effects in noun naming (** $p < .01$, * $p < .05$)

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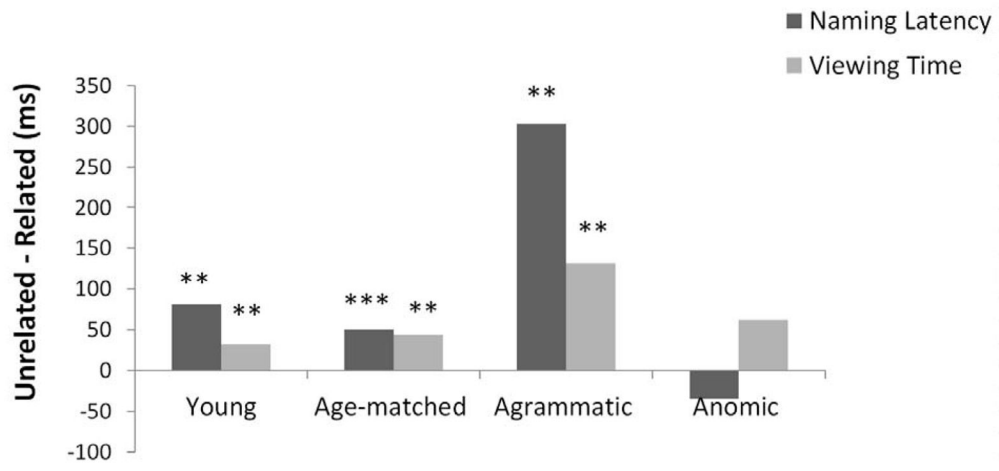


Figure 4. Phonological facilitation effects in verb naming (***) $p < .001$, ** $p < .01$).

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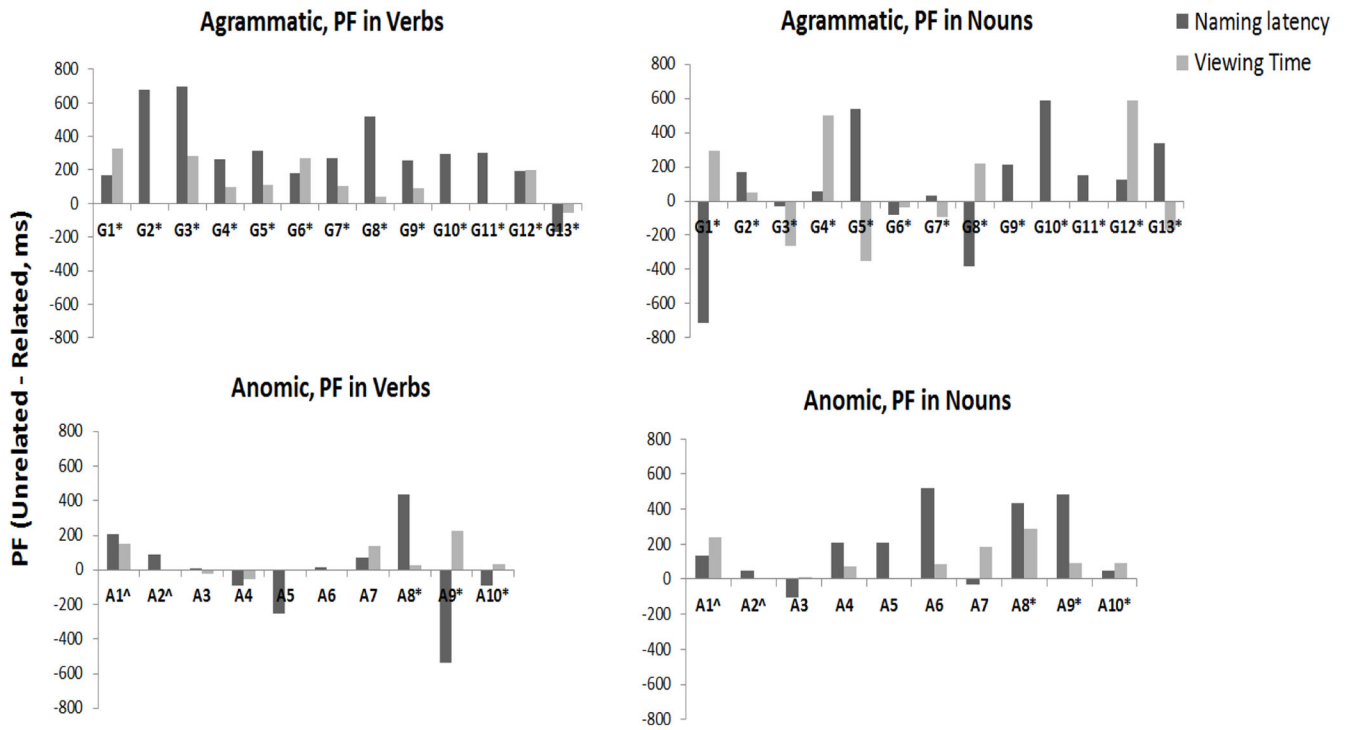


Figure 5. Phonological facilitation (PF) for nouns and verbs for individual participants in Experiment 2 as a function of performance in Experiment 1 (G = Agrammatic participants; A = Anomic participants). Positive bars indicated facilitation and negative bars indicate inhibition. Participants who show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

Table 1

Language testing scores for agrammatic and anomia participants

Participants	WAB-R				NAVS				NAVI		
	AQ	Fluency	AC	Rep	Naming	SPPT-C	SPPT-NC	SCT-C	SCT-NC	Nonfinite	Finite
<i>Agrammatic participants</i>											
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
<i>Anomia participants</i>											
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

Participants	AQ	Fluency	WAB-R			NAVS			NAVI		
			AC	Rep	Naming	SPPT-C	SPPT-NC	SCT-C	SCT-NC	Nonfinite	Finite
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

Note: 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

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)
<i>p</i> -value	n.s.	< .001	n.s

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Table 3

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

Error type	<u>Agrammatic participants</u>		<u>Anomic participants</u>	
	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%)
Non-word	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%)

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

Table 4

Participants	Naming Accuracies (%)			Naming Latencies (ms)			Viewing Times (ms)		
	Related	Unrelated	<i>p</i> -value	Related	Unrelated	<i>p</i> -value	Related	Unrelated	<i>p</i> -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)	**

* *p* < .05,

** *p* < .01

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

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

*** $p < .01$,

*** $p < .001$