Effects of verb overlap on structural priming in dialogue: implications for syntactic learning in aphasia

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Abstract

Purpose. Although there is increasing interest in using structural priming as a means to ameliorate grammatical encoding deficits in persons with aphasia (PWAs), little is known about the precise mechanisms of structural priming that are associated with robust and enduring effects in PWAs. Two dialogue-like comprehension-to-production priming experiments investigated whether lexically independent (abstract structural) priming and/or lexically (verb) specific priming yields immediate and longer, lasting facilitation of syntactic production in PWAs.

Method. Seventeen PWAs and 20 healthy older adults participated in a collaborative picture-matching task where participant and experimenter took turns describing picture cards using transitive and dative sentences. In Experiment 1, a target was elicited immediately following a prime. In Experiment 2, 2 unrelated utterances intervened between a prime and target, thereby allowing us to examine lasting priming effects. In both experiments, the verb was repeated for half of the prime–target pairs to examine the lexical (verb) boost on priming.

Results. Healthy older adults demonstrated abstract priming in both transitives and datives not only in the immediate (Experiment 1) but also in the lasting (Experiment 2) priming condition. They also showed significantly enhanced priming by verb overlap (lexical boost) in transitives during immediate priming. PWAs demonstrated abstract priming in transitives in both immediate and lasting priming conditions. However, the magnitude of priming was not enhanced by verb overlap.

Conclusions. Abstract structural priming, but not lexically specific priming, is associated with reliable and lasting facilitation of message–structure mapping in aphasia. The findings also suggest that implicit syntactic learning via a dialogue-like comprehension-to-production task remains preserved in aphasia.

Introduction

Decades of psycholinguistic research have established that structural priming – a speaker's tendency to echo previously encountered (heard or produced) message-structure associations – is pervasive in unimpaired speakers, reflecting cognitive processes that support efficient language processing and the mechanisms of language learning (Chang, Dell, & Bock, 2006; Ferreira & Bock, 2006; Mahowald, James, Futrell, & Gibson, 2016; Pickering & Ferreira, 2008). There is a growing interest in studying structural priming as a means to ameliorate impaired grammatical encoding processes in persons with aphasia (PWA). As yet, little is known about the precise mechanisms of structural priming that are associated with robust and/or enduring effects in the aphasic system. This study aims to address this significant gap by investigating the effects of verb overlap on immediate and longer-lasting structural priming in a dialogue-like comprehension-to-production priming task in PWA.

Structural priming is multifactorial in normal language processing, modulated by various factors. Earlier studies have identified that the locus of priming is at the level of abstract structural representations dictating the order of sentential constituents, independent of lexical-semantic content (i.e., *abstract priming*, henceforth; Bock, 1989; Bock & Loebell, 1990). For example, speakers are equally likely to produce passive structures (*the mailman was chased by a dog*) whether primed with a passive construction (*the man was struck by lightning*) or a sentence with a locative prepositional phrase (*the man drove the car to the office*). This indicates that the phrasal combinatorial nodes of a prime are sufficient to bias future production preferences in speakers, even in the absence of shared lexical-semantic content between the prime and the target (Bock & Loebell, 1990). However, later studies have shown that structural priming implicates levels of non-syntactic representations, such as lexical items (e.g., Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; Pickering & Branigan, 1998; Scheepers, Raffray, & Myachykov, 2017) and event-semantic content (Gruberg, Ostrand, Momma, & Ferreira, under review; Lee, Man, Ferreira, & Gruberg, under review, for aphasic data).

Most relevant to the current study, a body of literature clearly demonstrates that the magnitude of priming becomes significantly greater when lexical items, in particular lexical heads (e.g., verb), are repeated between prime and target compared to when there is no lexical overlap (Branigan & McLean, 2016; Branigan, Pickering, Stewart, & McLean, 2000; Cleland & Pickering, 2003; Hartsuiker et al., 2008; Pickering & Branigan, 1998; Schoonbaert, Hartsuiker, & Pickering, 2007). This *lexical boost* effect indicates the presence of a separate mechanism of priming that is lexically-driven in nature and that the production system benefits from repeated lexical information. Importantly, however, these lexically specific and independent priming mechanisms differ in their time courses. Abstract priming is overwhelmingly consistent over intervening linguistic materials and time intervals, suggesting that it creates sustaining changes in the system (Bock, Dell, Chang, & Onishi, 2007; Bock & Griffin, 2000; Cleland & Pickering, 2006; Kaschak, 2007). In contrast, at least in the domain of sentence production, the lexical boost effect is generally short-lived, dissipating over just a few intervening utterances (Branigan & McLean; 2016; Hartsuiker et al., 2008 and others; but see Pickering, McLean, & Branigan, 2013 for evidence of lasting lexical boost in sentence comprehension).

Researchers have proposed that these effects of structural priming are consequences of language learning (Bock et al., 2007; Chang, Dell, & Bock, 2006; Chang, Janciauskas, & Fitz, 2012; Fine & Jaeger, 2013; Reitter, Keller, & Moore; 2011; see Pickering & Ferreira, 2008, for discussion of other accounts of structural priming). The dual-path model instantiated by Chang and colleagues holds that error-based implicit learning in the syntactic sequencing (word order) system underlies abstract priming effects (Chang, Dell, & Bock, 2006; Chang, Janciauskas, & Fitz, 2012; see also Bock & Griffin, 2000). During incremental comprehension of a prime sentence, the individual predicts the next word. When a different word order is encountered (e.g., V NP PP when V NP NP is predicted), this discrepancy (error) is used to adjust connection weights in the system, causing small but persisting changes in future production choices. On the other hand, the lexical boost is attributed to short-term memory based retrieval in the lexical-semantic system. The repeated lexical item serves as a retrieval cue for the lemma and its link to the associated structural representations in short-term memory, yielding a temporary increase in priming.

In a different model, Reitter and colleagues (2011) attribute structural priming to activation-based learning in declarative memory. Lasting abstract priming is a result of both base-level learning and spreading activation in the memory system. When a linguistic representation is retrieved from memory, there is spreading activation to related representations. Although the activation decays to some degree over time, repeated retrieval of a structure changes its base level activation, resulting in persisting facilitation over time. However, a lexical boost effect is purely due to spreading activation from a retrieved lexical item to its related syntax, facilitating their subsequent use only. While these models differ in terms of specific cognitive constructs that are assumed to underlie the priming effects, they agree that both lexically independent and specific mechanisms of structural priming operate in the normal system (see also Branigan & McLean, 2016). However, it has not yet been clearly examined if this holds true in the aphasic production system.

Structural priming operates not only across linguistic levels but also across different communicative experiences. Non-linguistic factors such as communication contexts or the speaker's participation role in conversations also influence magnitudes of priming (Branigan et al., 2000; Branigan, Pickering, McLean, & Cleland, 2007; Pickering & Garrod, 2004; Reitter & Moore, 2014). Speakers show a particularly strong tendency to align syntactic structures with their interlocutor in a dialogue-like task, the most natural form of communication, compared to a single-speaker priming task. Branigan et al. (2000), for example, used a confederate scripted task where the participant and confederate partner took turns describing dative action-depicting picture cards with the goal of finding identical pictures. After just hearing their interlocutor's sentences during the 'game', the participants showed 55% and 17.5% priming effects in the same-verb and different-verb prime conditions, respectively. These effects were notably greater than 17.5% and 4.4 % priming effects found in Pickering & Branigan (1998)'s single-speaker task, where the participants were presented with booklets of sentence fragments to silently read and complete, including sequences of a same vs. different verb prime fragment followed by a target fragment designed to elicit a dative structure. This robust priming in dialogue is proposed to support ease of information transfer in a goal-based interactive task by creating shared 'routines' or situational models between interlocutors (Pickering & Garrod, 2014; see also Reitter & Moore, 2014) or by reducing the discrepancy between the structures that conversational partners expect to hear and the structures that they actually encounter (Jaeger & Snider, 2013). The strong priming effects in dialogue also revealed that structural priming does not require speakers to produce the prime structure prior to target production. Instead, comprehension (or listening)-based input is sufficient to modify preferences in message-syntactic associations in the production system, indicating a strong parity in the syntactic processing system between comprehension and production modalities (Bock et al., 2007; Branigan et al., 2000; Chang et al., 2006).

Impaired ability to map a message onto a syntactic structure is pervasive in persons with aphasia (PWA), regardless of aphasia types (Caramazza & Berndt, 1985; Caramazza & Miceli, 1991; Lee & Thompson, 2011a; 2011b; Lee, Yoshida, & Thompson, 2015; Maher et al., 1995; Miceli, Silveri, Romani, Caramazza, 1989; Saffran, Schwartz, & Marin, 1980a; Thompson, Faroqi-Shah, & Lee, 2015 for review). Sentences requiring rather complex grammatical computations to represent event relationships (e.g., who is doing what to whom) are particularly difficult to comprehend and/or produce for PWA. Those sentences include, for example, semantically reversible sentences (e.g., *the girl is chasing after the boy* as opposed to irreversible sentences such as *the girl is chasing after the ball*), sentences with a non-canonical word order (e.g., passives vs. actives), as well as sentences involving projection of complex verb argument structures (e.g., datives vs. intransitives) (Bastiaanse & Zonneveld, 2005; Cho-Reyes & Thompson, 2012; Howard, 2001, 2004, & 2007; McAllister, Bachrach, Waters, Michaud, & Caplan, 2009; Saffran, Schwartz, & Marin, 1980a; Saffran, Schwartz, & Marin, 1980b; Thompson, 2003; Thompson, Lange, Schneider, & Shapiro, 1997; Webster, Franklin, & Lee & Thompson, 2004). Consequently, identifying ways to ameliorate the mapping deficits has been an important question in both experimental and intervention studies with PWA. However, only a few empirically well-tested treatment approaches are available so far. For example, Mapping Therapy and Treatment of Underlying Forms (TUF) were developed to explicitly teach PWA to use linguistic rules (e.g., syntactic movement) to 're-map' underlying semantic representations onto surface syntactic representations (e.g., Rochon, Laird, Bose, & Scofield, 2005; Schwartz, Saffran, Fink, Meyers, & Martin, 1994; Thompson & Shapiro, 2005; Thompson, Shapiro, Kiran, & Sobecks, 2003).

There is growing evidence that implicit structural priming could also facilitate grammatical encoding processes in aphasia (Cho-Reyes, Mack, & Thompson, 2016; Hartsuiker & Kolk, 1998a; Lee & Man, 2017; Lee, Man, Ferreira & Gruberg, under review; Rossi, 2015; Saffran & Martin, 1997; Verryt, Bogaerts, Cop, Bernolet, De Letter, Hemelsoet, Santens, & Duyck, 2013; Yan, Martin, & Slevc, 2018). PWA show increased production of moderately complex sentences (e.g., passives, datives) immediately following prime sentences that are often absent in their spontaneous speech, although the priming effects are not always statistically reliable (Hartsuiker & Kolk, 1998a; Saffran & Martin, 1997; Yan et al., 2018). For example, in the seminal studies of structural priming in aphasia, Saffran & Martin (1997) found significant priming for transitives but not for datives in a group of participants with mixed aphasia types, whereas Hartsuiker and Kolk (1998a) found significant priming effects for both transitives and datives in participants with agrammatic aphasia. More recent evidence suggests that priming can create enduring effects in PWA (Cho-Reyes et al., 2016; Lee & Man, 2017; see also Lee, Man, Ferreira, & Gruberg, under review; cf. Schuchard, Nerantzini, & Thompson, 2017). Cho-Reyes et al. (2016) reported persistent abstract priming over as many as 4 intervening fillers in agrammatic aphasia. Lee & Man (2017) reported an individual with agrammatic aphasia (MJ), who showed a significantly improved ability to spontaneously produce prepositional-object dative sentences following structural priming training. In addition, the improvement was maintained at four weeks post training.

Collectively, the emerging evidence from the prior studies suggests that syntactic representations are preserved in PWA, though they may not be easily accessible for PWA during sentence production (Kolk, 1995; Kolk & Heeschen, 1992; Kolk & Van Grunsven, 1985; Lee, Yoshida, & Thompson, 2015; Linebarger, Schwartz, Romania, Kohn, & Stephens, 2000; Linebarger, Schwartz, & Saffran, 1983). Structural priming could facilitate activation and selection of target syntactic structures in PWA, suggesting that it could be used as an intervention technique for remediating grammatical encoding deficits in aphasia. However, as yet, it remains largely unknown what linguistic and non-linguistic factors modulate strength and longevity of structural priming in aphasia. Without this knowledge established, effective use of structural priming as a remediation strategy for PWA would be limited.

We do not know, for example, whether a dialogue-like comprehension-to-production task effectively generates positive and enduring priming in PWA, as shown in unimpaired speakers. Most previous studies in aphasia used a single-speaker experimental task where the participant would orally repeat or read a prime sentence prior to target production (Cho-Reyes et al., 2016; Hartsuiker & Kolk, 1998a; Lee & Man, 2017; Saffran & Martin, 1997; Yan et al., 2018; but see Rossi, 2015; Verreyt et al., 2013, for non-production tasks). In a recent study, Lee et al. (under review-a) found that PWA could re-use their interlocutor's syntactic structures in their own production in a collaborative picture-matching game involving a blocked priming design. Interestingly, the priming effect was found when the PWA orally repeated the prime sentences they heard (interlocutor's picture descriptions) during the picture matching (prime) block prior to the production block, but not when the primes were processed in listening only, that is in a comprehension-to-production task. However, the use of a blocked priming design in Lee et al.'s study naturally created a lag of approximately 10-12 intervening utterances between the prime and target (see Lee et al., under review-a for details). The participants first processed a block of 12 different prime sentences (a mix of 4 transitive, 4 dative, and 4 locative alternations) prior to their turn to produce 12 target sentences (production block). This lag is substantially greater than 0-2 lags used in most dialogue-based priming studies in young adults and children (e,g., Branigan & McLean, 2016; Peter, Chang, Pine, Blything, & Rowland, 2015; Rowland, Chang, Ambridge, Pine, & Lieven, 2012). Thus, it remains unclear whether the null results from Lee et al.'s comprehension-to-production task were due to the experimental design, or if prior linguistic experiences based solely on comprehension are insufficient to modify message-structure mappings in the aphasic production system. A dialogue task involving a shorter lag would allow us to tease this apart.

We also do not know if and to what extent short-term and longer-term priming effects are modulated by lexically specific and independent primes in aphasia. There is only one study by Yan and colleagues (2018) that has examined and found a lexical boost effect during sentence production in PWA. Their PWA demonstrated a significantly greater priming effect on production of transitive sentences when the verb was repeated between prime and target. In addition, the magnitudes of lexical boost effects (as well as abstract priming effects) were comparable between PWA and healthy older adults (HOA). However, the study examined only sentences with transitive (active/passive) alternations and the target sentence was elicited immediately following the prime. In addition, they used a single-speaker priming task where the participant orally repeated an auditorily-presented prime sentence and then read a written version of the prime to verify if their repetition was correct. This two-step priming might have encouraged the participant to better encode and re-use the lexical-semantic materials of the prime. Different from Yan et al.'s findings, we (Lee, Hosokawa, Meehan, Martin, & Branigan, under review) failed to find a lexical boost effect during comprehension of syntactically ambiguous sentences. However, the PWA still demonstrated abstract priming not only in the immediate priming condition (0-lag) but also over 2 intervening utterances (2-lag). Therefore, further investigation is needed to better understand if the lexical boost and/or independent abstract structural priming are truly preserved and persistent mechanisms in aphasia.

The purpose of the present study was, therefore, to systematically investigate a set of important questions on structural priming in aphasia, with the long-term goal of delineating factors associated with robust and/or long-lasting priming effects in aphasia. We first asked whether PWA demonstrate significant structural priming in a dialogue-like comprehension-to-production task. We used a collaborative picture-matching task in both experiments, where the participant took turns describing pictures with an experimenter with the goal of finding identical ('Bingo') picture cards in both experiments. It was predicted that PWA would show significant priming in our task, if comprehension-based priming is sufficient to change their structural preferences during sentence production.

If PWA showed priming in dialogue, our second question was to examine whether both lexical boost and abstract priming are preserved in PWA, as found in Yan et al. (2018), or whether they demonstrate only abstract priming, as found in Lee et al. (under review-b). Thus, Experiment 1 examined the effects of same-vs. different-verb primes on the production of transitive and dative alternations when the target sentence was elicited immediately after the prime, i.e., immediate priming (0-lag). Importantly, we included not only transitive but also dative target sentences, thereby allowing us to further examine the generalizability of the priming effects across different structures. PWA were expected to demonstrate abstract priming effects in immediate priming, consistent with previous structural priming studies in production (Cho-Reyes et al., 2016; Hartsuiker & Kolk, 1998a; Saffran & Martin, 1997) and comprehension (Lee et al., under review-b). If lexically-specific immediate priming is also preserved in aphasia, PWA were predicted to show a significantly greater priming effect in the same-verb prime condition than in the different-verb prime condition (Yan et al., 2018). Finally, we examined the time courses of abstract priming and lexical boost effects to elucidate learning of grammatical encoding in aphasia. To address this question, Experiment 2 replicated Experiment 1 with one modification: Two filler trials interceded between prime and target, thereby allowing examination of lasting priming effects. Following Lee et al. (under review-b), it was predicted that our PWA might show persistent abstract priming but no lexical boost over intervening fillers.

Experiment 1

Experiment 1 used a dialogue-like picture-matching game to examine if comprehension-to-production priming is preserved in aphasia when the target was elicited immediately following the prime. Participants took turns with the experimenter describing picture cards with the goal of finding matching ('Bingo') pictures. To test if HOA and PWA show a lexical boost effect, half of the prime-target pairs contained the same verb, whereas the other half contained different verbs.

Methods

Participants. Seventeen PWA (4 females, 13 males; age mean = 63.1 years, range 52 - 80, education mean = 14.5 years, range 10 - 20) were included in the present study. In addition, 20 healthy older adults (HOA; 13 females, 7 males; age mean = 70.7 years, range 60 – 82; education mean = 16.5 years, range = 12 - 23) were recruited as control participants. All participants were monolingual native speakers of English and reported no history of neurological or psychological disorders prior to stroke or study participation that could affect communication. All reported normal or corrected-to-normal vision, and passed a hearing screening at 500, 1000, and 2000 Hz at 40dB in at least one ear. HOA's cognitive-linguistic abilities were screened using the Cognitive Linguistic Quick Test (Helm-Estabrooks, 2001). All HOA scored within normal limits for their age, indicating that there were no significant age-related changes in their attention, memory, executive function, language, and visuospatial skills (Composite Severity Rating Mean (SD) = 3.98 (.06), normal range: 3.5 - 4.0). Participants were compensated for their time and provided informed consent prior to the study. All HOA were tested at Purdue University, while PWA were tested at Purdue University and Temple University. The study was approved by the Institutional Review Boards of these universities.

PWA had a diagnosis of aphasia following a left CVA at least 6 months prior to the study except for one PWA who suffered a stroke 2 months prior (M (SD) = 75 (46) months). A battery of cognitive-linguistic tests was administered with PWA, as shown in Table 1. Given the nature of the current experimental task, participants with mild-to-moderate fluent or non-fluent aphasia as demonstrated by an Aphasia Quotient greater than 60 on the Western Aphasia Battery-Revised were included (WAB-R AQ range 66.8 – 97.4, Kertesz, 2006). All participants demonstrated preserved ability to comprehend single words and simple sentences, as indicated by an average score of 5/10 in the Auditory Comprehension section of the WAB-R, 80% on the Verb Comprehension Test (VCT), and above chance-level on the comprehension of canonical sentences of the Sentence Comprehension Test (SCT_C) of the Northwestern Assessment of Verbs and Sentences (NAVS; Thompson, 2011). In order to ensure that the participants have preserved ability to produce at least some canonical sentences, we included those who scored at least 4/10 on the Fluency section of the WAB-R, minimum 50% correct on the Verb Naming Test (VNT) and the Argument Structure Production Test (ASPT) of the NAVS. On the Sentence Production Priming subtest of the NAVS, as a group, PWA produced canonical sentences more correctly than non-canonical sentences (72% vs. 47%), consistent with marked difficulty with syntactically complex sentences in both fluent and nonfluent aphasia (Cho-Reyes & Thompson, 2012).

[insert Table 1 here]

In addition, participants' lexical-semantic short-term memory was measured using two subtests of the Temple Assessment of Language and Short-Term Memory in Aphasia (TALSA; Martin, Kohen, & Kalinyak-Fliszar, 2010) as shown in Table 2: Category Probe Span and Synonymy Triplet 3-word and 2-word. These tests assess one's ability to hold a set of words in short-term memory while judging semantic category membership of a target word or selecting a semantically related word to a target word (see Martin, Kohen, Kalinyak-Fliszar, Soveri, & Laine, 2012; Martin, Minkina, Kohen, & Kalinyak-Flizsar, 2018, for detailed descriptions of the tests). Three out of 17 PWA could not complete the TALSA due to time constraints. PWA performed significantly worse than HOA on all three subtests (*t's* (30) < 2.3, *p's* < .05). This pattern is consistent with previous findings that lexical-semantic STM impairments are common in aphasia (Allen, Martin, & Martin, 2012; Barde, Schwartz, Chrysikou, & Thompson-Schill, 2010; Martin & Ayala, 2004).

[insert Table 2 here]

Materials and design. For transitive stimuli, a set of 48 target and 48 prime sentences and their corresponding black-and-white line drawings were taken from Branigan and McLean (2016). The pictures depicted an animal agent and human theme in one of the six actions (*bite, chase, kiss, lift, pull, push*; see Figure 1 for an example stimulus). Each verb was used 8 times in the prime pictures, and 8 times in the target pictures with different agent-theme pairs. For dative stimuli, another set of 96 (48 targets and 48 primes) sentences and associated pictures were taken from Branigan's stimuli bank. These stimuli effectively elicited priming effects in young adults in previous studies (e.g., Branigan, Pickering, & Cleland, 2000). The dative pictures depicted a human agent and goal and an inanimate theme in one of the six actions (*give, hand, offer, sell, show, throw*). Each verb was used in 8 prime pictures and in 8 target pictures. The target verb and nouns were written on the picture card in order to minimize confounding effects on sentence production from word-retrieval difficulties of PWA (see Figure 1). The picture stimuli were printed as 4 1/2 x 3 2/3 inch cards on card stock paper.

Each transitive target picture was paired once with an active prime and once with a passive prime. Likewise, each dative picture was paired once with a prepositional-object (PO) prime and once with a double-object (DO) prime. In addition, within the target structure, half of the prime-target pairs had the same verb and the other half had different verbs. Therefore, each target picture was elicited four times across four different prime conditions, as demonstrated in Table 3. Prime and target items were paired carefully so that there was no overlap in the phonological and semantic content of the nouns used between prime and target. Additionally, a total of 192 intransitive sentences and corresponding pictures were prepared for fillers. Of these 192 fillers, 31 were used as the 'Bingo' items. The bingo items involved identical picture cards between experimenter and participant's card stacks, and were included to ensure that the participants actively attended to the task.

[insert Table 3 here]

Four lists were created for the experiment. Each list consisted of a total of 96 experimental trials, including 48 transitive prime-target pairs and 48 dative prime-target pairs, and 192 filler trials. Each target picture was presented only once within the list, paired with one of the four different primes across the four lists. For example, the target transitive picture *the* *tiger is biting the fireman* was paired with the same verb-active prime *the rabbit is biting the doctor* in list 1, but with a same-verb, passive prime *the doctor is being bitten by the rabbit* in list 2 and so on. The order in which experimental trials were presented within each list was pseudo-randomized such that no same prime condition (transitive or dative primes) was presented in two consecutive trials. In addition, two filler trials were presented after each experimental trial. Each participant received only one list. The order of the list was counterbalanced across the participants.

Procedure. Prior to the experimental task, all participants were familiarized with the target and filler nouns and verbs as singletons using a stimulus book. This was done to minimize the influence of aphasic participants' word-retrieval difficulties on the sentence production task. For nouns, the participants were shown a stimuli book including a set of black-and-white drawings of the characters and objects with their names written (e.g., 'rabbit') underneath and were asked to name them. For verbs, participants were asked to read written verbs ('bite') without any associated drawings. Feedback was provided for any errors produced.

For the experimental task, the experimenter and participant played a picture-card matching game with the goal being to find the matching (Bingo) pictures, as demonstrated in Figure 1. The experimenter and participant each had a stack of cards in front of them face down on the table. The experimenter's stack contained the prime and filler cards, and the participant's stack contained the target and filler cards. The participants were told that they would be playing a card game called "Bingo", where they would take turns turning over their top card and describing each picture with a single complete sentence using all the words on the card. When the experimenter and participant had cards that were identical, the participant was required to say "Bingo!". The experimenter always described their picture first, and produced different types of prime sentences following a color cue marked on the bottom right corner of the prime picture card (pink = PO, blue = DO, green = active, orange = passive). There was no color cue on the participants' picture cards such that the participant was unaware of the prime manipulation. A set of four practice trials preceded the game. The participants' responses were audio recorded for data analysis.

[insert Figure 1 here]

Data coding and analyses. Participants' responses were transcribed verbatim and each response was coded as a 'correct' or 'incorrect' target response. A response was considered as 'correct' if it included all the target nouns and the verb in one of the alternating target structures (active or passive for transitives; PO or DO for datives). When multiple attempts were made, the final sentential response was scored. When a subject noun phrase and a verb predicate were produced minimally (e.g., *the man was chased*), the response was considered as a sentential response. Production of synonyms (e.g., *boy* for *man*), intelligible phonological paraphasias, omission of articles, and disfluencies (e.g., fillers, self-corrected responses) were accepted. For actives, the response had to be in the NP (agent) V NP (theme) constituent order to be considered 'correct', with variances in verb tense forms (*lifted, is lifting, lifts*) permitted. A correct passive response had to contain the theme in the pre-verbal position, the agent in the post-verbal position preceded by the preposition 'by'. With regard to the verbal morphology of passive responses produced by PWA, we accepted omission of an auxiliary verb (*the doctor lifted by the lion*) or production of non-past participle form of the verb (e.g., *pushing*, *push* for *pushed*), following prior studies using 'lenient' scoring with PWA (Hartsuiker & Kolk, 1998a, Saffran & Martin, 1997; see also Branigan & McLean, 2016, with children).[1] For HOA, only responses with correct

[1]These 'lenient' criteria applied to only four percent (6/153) of all correct passive responses produced by PWA.

passive verbal morphology (auxiliary + past participle) were considered as ‘correct’. For a PO structure, production of semantically legitimate prepositions in the prepositional phrase (PP) that can be used with an animate noun (*for, to, with*) were accepted but not the prepositions that are more generally used with an inanimate noun (*in, at, on*). Phonological paraphasias were accepted if 50% or more phonemes of a target word were intelligible.

The following responses were considered as ‘incorrect’ responses: role-reversal errors in which thematic roles were reversed in the target structure (e.g., *lion is being lifted by doctor* for *the doctor is being lifted by the lion*), verb argument structure errors, including omitted or incorrectly produced arguments (e.g., *pushed by a cat* for *the fireman is being pushed by a cat; a priest is handing a pitcher a boxer* for *a priest is handing a pitcher to the boxer*), and off-target verb and noun substitutions (e.g., *feeding* for *handing; chef* for *artist*). Non-sentence responses (e.g., *professor is apple… apple a doctor*) and sentence responses with a non-target structure (e.g., *the soldier is being handed a pitcher by a ballerina* for the PO target *the ballerina is handing a pitcher to the soldier)* were also excluded as well as unintelligible or ‘I don’t know’ responses.

The analysis of priming effects was conducted based on ‘correct’ target responses only. The priming effect was defined as the increased production of an arbitrarily selected structural alternative (i.e., active for transitive targets; PO for dative targets in this study) following the same vs. the alternative prime structures. In other words, the priming effect for transitives was the increased proportion of active sentences produced following an active prime vs. following a passive prime. The proportion of active responses in each prime condition was calculated for each participant by dividing the number of active responses in that condition by the total number of active plus passive responses in that condition. Similarly, the priming effect for dative targets was the increased proportion of PO sentences produced following a PO prime vs. following a DO prime. The proportion of PO responses in each prime condition was calculated for each participant by dividing the number of PO responses in that condition by the total number of PO and DO responses in that condition.

Statistical analysis. To compare group differences on production of 'correct' responses, we used a 2 (group) x 2 (prime type) x 2 (verb type) mixed ANOVA within each target structure. Statistical analyses of priming effects were conducted using mixed-effects logistic regression to compare probability of a specific response (an active response for transitives; a PO response for datives) in the different prime conditions (*lme 4* package, Bates, Maechler, Bolker, & Walker, 2014; Jaeger, 2008). A series of models were used for each target structure. Data were first modeled including both groups in order to compare priming effects between the groups. These models included prime, verb, group, and their 2- and 3-ways interactions as fixed factors. Secondly, a separate model was used for each participant group in order to test for priming effects across conditions. In these models, prime, verb, and their interactions were entered as fixed factors. For all the models, the random effects structure included by-participant and by-item intercepts as well as by-participant and by-items slopes for all main effects. In addition, whenever relevant, we calculated effect sizes of the priming effects (Cohen's *d*) for each condition within participant group to directly compare magnitudes of priming between the groups while factoring out differences in variability (Cohen, 1992; Dunlap, Cortina, Vaslow, & Burke, 1996).

Results & summary

For HOA, we excluded 15 responses from a total of 1,920 responses due to experimental errors, resulting in a total of 1,905 scorable responses. For PWA, eight responses were excluded from a total of 1632 due to experimental errors, resulting in a total of 1,624 scorable responses.

Accuracy analysis. Table 4 summarizes proportions of accurate target responses produced for each participant group for different prime conditions. For transitive targets, only the group effect was significant, indicating that PWA produced significantly fewer accurate target responses in general (PWA: 77 % vs. HOA: 99%; F (1, 35) = 16.34, p < .001). The main effects of verb and prime and any of the 2- and 3-way interactions were not reliable (F's < .97). Similarly, for dative targets, PWA produced fewer accurate responses compared to HOA in general (PWA: 87 % vs. HOA: 99%; F (1, 35) = 8.79, p = .005). No other main effects or 2-way interactions were significant (F's < 2.45). The 3-way interaction was significant (F (1, 35) = 13.22, p = .001), indicating a larger group difference in accuracy for same-verb trials in the PO prime condition, but a larger group difference in accuracy for different-verb trials in the DO prime condition. However, this interaction has no theoretical bearing, thus, we do not discuss it further.

Error types were tallied. For transitive targets, the most common errors produced by PWA were role reversal errors (61%, e.g., *the boy is biting the rabbit* for *the rabbit is biting the boy*) followed by noun substitution errors (8%, e.g., *bear pulling a boy* for *the bear is pulling the girl*). For dative targets, PWA produced incorrect argument structure errors (41%, e.g., *cowboy… offers… banana… thief* for *the cowboy is offering the banana to the thief*) and noun substitution errors (16%; e.g., *The ballerina… hands… the pitcher to the sailor* for *the ballerina is handing the pitcher to the soldier*) most frequently.

[insert Table 4 here]

Priming analysis.[2] Figure 2 shows priming effects for transitive and dative targets in each group for Experiment 1. Figure 3 shows individual participants' magnitudes of priming effects for both PWA and HOA. The results of the mixed-effects models are summarized in Table 4. We first discuss the results from a mixed-effects model comparing the groups, followed by the results of a mixed-effects model for each participant group individually. For the *transitive targets*, the model comparing the group effects revealed a significant effect of prime type, indicating that participants were more likely to produce active structures following active than following passive primes. A significant effect of verb type indicated more active responses in the same- than in the different-verb prime condition. A main effect of group indicated greater production of active structures in PWA than in HOA. These two main effects provide no theoretical challenges. Among 2-way interactions, only the prime x verb interaction was significant, indicating increased priming for the same- vs. different-verb primes. Importantly, the 3-way (prime x verb x group) interaction was significant at $\alpha = .05$, indicating the lexical boost may be significant only in one group.

The mixed-effect model for HOA revealed significant main effects of prime type and verb type. Importantly, the interaction between prime type and verb type was significant, indicating a significantly greater priming effect in the same verb condition compared to the

[2] Because the participants completed both experiments (although the order of the experiments was counterbalanced and there was at least a 2-week interval between experiments), we ran a set of additional models to rule out the significant priming effects being influenced by some participants' prior completion of a similar experiment (practice effect). Experiment Order and Prime and their interaction were included as fixed factors. Only for the transitive targets of Experiment 2, Experiment Order interacted with Prime, but in the direction that those who completed Experiment 2 first showed greater priming effects than those who completed Experiment 1 first ($p < .01$). Therefore, the results are unlikely to be due to practice effects.

different verb condition. HOA produced on average 47% more active responses following active compared to passive primes in the same verb condition (*d* = 2.02). When different verbs were used between prime and target, HOA produced on average 25% more active responses following active compared to passive primes (*d* =1.40). For PWA, however, only the effect of prime type was significant. They showed numerically greater priming following the same-verb primes (mean 15% difference, *d* = .74) compared to the different-verb primes (mean 10% difference, *d* = .72), but this difference was not significant. Although there was substantial individual variability in magnitude of priming (Figure 3), PWA in general showed relatively similar priming effects between the same and different verb conditions. HOA also showed substantial variability in magnitude of priming overall, but demonstrated greater priming effects for the same verb versus different verb condition.

For the *dative targets*, the mixed-effects model comparing groups revealed a significant effect of prime type, indicating overall increased PO responses following PO versus DO primes. Overall there was increased production of PO responses in PWA compared to HOA, as indicated by a significant group effect. The main effect of verb type was not significant. There was a significant prime by group interaction, indicating greater priming effects in HOA than in PWA. No other 2-way interaction was significant. Lastly, there was a significant prime type x verb x group interaction.

The results of a mixed-effects model for HOA revealed a significant effect of prime type only, but no effect of verb type. The interaction between prime type and verb type did not reach significance, although HOA showed a larger effect size in priming when the same verb condition (mean 18% difference, *d* = 1.03) compared to the different verb condition (mean 11% difference, *d* = .76). On the other hand, PWA failed to show any significant effect of prime type, verb type, or interaction between the two in datives. PWA showed a negative priming effect in the same verb condition (mean – 0.67% difference, *d* = .00) and a small priming effect in the different verb condition (mean 4% difference, *d* = .35) (see Figure 3 for HOA and PWA individual data).

[insert Figure 2 here]

[insert Table 5 here]

[insert Figure 3 here]

To summarize the results from Experiment 1**,** PWA showed clearly different patterns of results from HOA. For HOA, both abstract priming and lexical boost were significant in transitive targets, and only abstract priming was significant for dative targets. However, PWA demonstrated only abstract priming in transitive targets, and no priming in dative targets.

Experiment 2

Experiment 2 examined whether PWA and HOA demonstrate persisting priming effects over intervening utterances. Thus, two intransitive filler items were embedded between the prime and target. The rest of the experiment remained the same as in Experiment 1.

Methods

Participants. The same 17 PWA and 20 HOA who participated in Experiment 1 participated in Experiment 2 with a minimum of 2 weeks between experiments. The order in which the participants completed the two experiments was counterbalanced.

Materials, procedure, and data analyses. The same experimental materials, procedures, and data analyses were followed from Experiment 1 with one modification: Each prime-target pair included two intervening filler items. That is, during the picture-matching game, each trial consisted of a prime picture (described by the experimenter), a filler picture (described by the participant), a filler picture (described by the experimenter), and a target picture (described by the participant).

Results and summary

For HOA, eight responses were excluded from a total of 1,920 responses due to experimental errors, resulting in 1,912 scorable responses. For PWA, 12 responses were excluded from a total of 1,632 responses due to experimental errors, resulting in 1,624 scorable responses.

Accuracy analysis. Table 4 shows proportions of accurate target responses for Experiment 2. For transitive targets, only the group effect was significant, indicating that PWA produced significantly fewer accurate target responses overall (PWA: 80% vs. HOA: 99%; F (1, 35) = 1447.600, $p < .001$). The main effects of verb and prime and any of the 2- and 3-way interactions were not significant (F's < .63). Similarly, for dative targets, PWA produced fewer accurate responses compared to HOA overall (PWA: 87% vs. HOA: 99%; F (1, 35) = 2170.98, $p < .001$). No other effects were significant (F's < 2.56). Error analysis revealed that PWA produced role reversal errors (65%) and 'other' type errors (12%) most frequently for transitive targets. They produced incorrect argument structure errors (43%) and noun substitution errors (18%) most frequently for dative targets, similar to Experiment 1.

Priming analysis. The priming effects for HOA and PWA across different priming conditions are presented for each target structure in Figure 4. Figure 5 shows individual participants' magnitudes of priming effects. The results of the mixed-effects models are presented in Table 6. For *transitive targets*, the model comparing groups revealed that there was only a significant effect of prime type, indicating that more active responses were produced overall after active rather than after passive primes. No other main effects or 2- and 3-way interactions were significant, indicating that the priming effect did not vary as an effect of participant group or verb type. In the mixed-effects model of HOA, only prime type was significant. HOA showed a small but significant priming effect regardless of verb overlap, i.e., no lexical boost (5% difference for same-verb primes, d = .33; 5% difference for different-verb primes, d = .36). Similarly, PWA demonstrated a significant effect of prime type, but no effects of verb type or interaction between the two. They showed comparable priming effects between the same verb (mean 5% difference, d= .25) and different verb (mean7% difference, d = .41) conditions, with individual variability being greater in the different vs. same verb condition (Figure 5).

For *dative targets*, the model comparing groups revealed that only the effect of prime type was significant, indicating more PO responses were produced overall after PO primes than after DO primes. No other main effect or interaction was significant. Within-group models revealed that HOA showed comparably significant priming between the same-verb (4% difference, d = .22) and different-verb conditions (5% difference, d = .32), as indicated by the effect of prime type in the absence of a significant interaction between verb and prime type. Both effect sizes were small (Cohen, 1992). For PWA, the effect of prime type failed to reach significance again, similar to Experiment 1, although their mean magnitudes of priming effects appear to be similar to those seen in HOA (5% difference, d = .30 for same-verb primes; 4% difference, d = .24 for different-verb primes). This may be due to increased variability in the data from PWA (Figure 5). In addition, there was a significant effect of verb type, but no significant verb x prime interaction.

[insert Figure 4 here]

[insert Table 6 here]

[insert Figure 5 here]

To summarize, when two unrelated utterances intervened between prime and target, HOA demonstrated small but significant abstract priming effects, but no lexical boost, for both transitive and dative target structures. Hence the lexical boost effect that HOA showed for transitives in Experiment 1 dissipated over 2 intervening sentences in Experiment 2. PWA showed significant abstract priming in transitives, with the effect being comparable to HOA. However, as in Experiment 1, PWA failed to show significant priming for dative targets. We now turn to implications of the current findings.

General Discussion

Structural priming effects have played a central role in revealing cognitive processes supporting efficient grammatical encoding as well as language learning in unimpaired speakers. Despite increasing interest in studying structural priming with PWA as a means to ameliorate their grammatical encoding deficits, it remains largely unknown if and how linguistic and non-linguistic factors influence the strength and longevity of priming in aphasia. To answer a set of important questions regarding the mechanisms of structural priming in aphasia, the present study examined the effects of same vs. different-verb primes on the production of transitive and dative sentences in a group of PWA and HOA. We examined these mechanisms in both immediate (0-lag, Experiment 1) and lasting (2-lag, Experiment 2) priming conditions.

The first question examined whether structural priming in aphasia remains preserved in a dialogue-like comprehension-to-production task. Our PWA showed significant priming effects at least for transitive sentences. This priming was observed not only in Experiment 1, but also over intervening linguistic material in Experiment 2. These findings provide the first evidence suggesting that comprehension-to-production priming remains preserved and operative in the context of dialogue for PWA beyond a single-speaker experimental task (as used in most previous studies with aphasia). The findings also inform our previous study (Lee et al., under review-a), where we failed to find significant priming for PWA in a comprehension only-based dialogue task. Because the current results demonstrated that the priming mechanism in a comprehension-to-production dialogue-like task is operative at least up to two intervening utterances for our participants with aphasia, it is most likely that the null results from Lee et al. (under review-a) are caused by the increased intervening linguistic material associated with the blocked priming paradigm. Further investigation is needed in order to more precisely delineate the extent to which priming is persistent in PWA in dialogue-like tasks. Nonetheless, the current findings overall suggest that comprehension-based prior linguistic experiences could effectively bias preferences in syntactic production in PWA indicating that abstract syntactic representations remain intact and are shared between modalities in aphasia (Branigan & Pickering, 2017; Lee et al., under review-b). Further, the ability to extract and re-use the message-syntax mappings from incoming auditory linguistic input remains preserved in PWA, consistent with previous evidence suggesting that the grammatical encoding deficits in aphasia are a result of inefficient information processing rather than a loss of linguistic representations (de Roo, Kolk, & Hofstede, 2003; Haarmann & Kolk, 1991; Kolk & Van Grunsven, 1985; Lee et al., 2015; Linebarger, Schwartz, Romania, Kohn, & Stephens, 2000).

The second question examined the mechanisms at work if PWA demonstrate priming in a dialogue-like context. More specifically, it was examined whether PWA show both lexically independent abstract priming and the verb-specific lexical boost when primes and targets are processed consecutively in Experiment 1, as shown in priming studies with unimpaired speakers, including young adults and children. The results revealed that only abstract priming is preserved for PWA, whereas both abstract priming and lexical boost (for transitives) are operative for HOA. HOA showed significant abstract priming in both transitives and datives. They also showed a robust lexical boost in transitives as evidenced by an average 23% boost in priming following same vs. different-verb primes. This is comparable to a 25.2% lexical boost found in older adults of Hardy et al (Hardy, Messenger, & Maylor, 2017) and a 23% lexical boost seen in children (Branigan & McLean, 2016) using a similar dialogue-like task. HOA showed a trend for lexical boost (7% increase) in datives, though the difference was not statistically significant.

In contrast to HOA, PWA did not show evidence of a lexical boost. Even when PWA showed robust abstract priming for transitives in Experiment 1, they showed an average of only 4% of verb-specific enhancement on priming. These results are consistent with our previous comprehension priming study, wherein PWA showed only abstract priming during interpretation of syntactically ambiguous sentences (Lee et al., under review-b). Furthermore, the findings suggest that the lexically-independent and lexically-specific structural priming effects are associated with distinctive cognitive processes (Chang et al., 2012; Reitter et al., 2011) and can be selectively affected in PWA. The lack of lexical boost may be attributed to PWA's deficits in spreading activation of lexical information (Reitter et al., 2011) or maintaining lexical-semantic information in short-term memory (Chang et al., 2006; 2012). Of relevance, our PWA showed significantly lower performance than HOA on the lexical-semantic short-term memory tests of the TALSA (Table 2; see also Allen et al., 2012; Barde et al., 2010; Martin & Ayala, 2004). However, Yan et al. (2018) found a significant lexical boost in PWA whose lexical-semantic short-term memory was impaired, highlighting the need for caution on this interpretation. As noted in the introduction, Yan et al. (2018) used a priming task where their PWA orally repeated the heard prime sentence and then read a written version to verify if their repetition was correct.

This increased depth of encoding for the prime sentences in their study might have allowed PWA to better activate and maintain the lexical information in memory and re-use it in subsequent sentence production more effectively than in the current study, compensating for their limitations in lexical-semantic short-term memory. Further investigation is needed to better delineate how task complexity and individuals' nature and severity in lexical-semantic processing modulate a lexically-specific boost in priming.

Thirdly, in Experiment 2, we investigated if priming effects are persistent over intervening linguistic material, to determine if comprehension-induced priming in a dialogue setting reflects enduring facilitation or 'learning' in syntactic production as proposed by previous studies with unimpaired speakers (Bock & Griffin, 2000; Chang et al., 2006; 2012; Reitter et al., 2011; see also Jaeger & Snider, 2013). The results of Experiment 2 by and large supported this view. For transitive targets, both HOA and PWA showed significant abstract priming effects over intervening utterances, though the effects were substantially smaller compared to Experiment 1 for both groups. The lexical boost effect that was significant in Experiment 1 for HOA dissipated over the intervening fillers in Experiment 2, consistent with previous production priming studies showing a short-lived time course of lexical boost in young adults and children (Branigan & McLean, 2016; Hartsuiker et al., 2008; Kaschak & Borreggine, 2008; Malhotra, Pickering, Branigan, & Bednar, 2008). Similarly, PWA continued to show abstract priming in transitives and, notably, they did not differ from HOA in the magnitude of priming, suggesting that lasting abstract priming in PWA is as effective as that in HOA. For dative targets, HOA continued to show small but reliable abstract priming, whereas the priming effect for PWA did not reach significance in the mixed-effects models (see below for discussion of the absence of priming effects in datives).

The preserved abstract priming effect over a lag found in our PWA, at least for transitives, suggests that simply hearing (and likely comprehending) the interlocutor's sentences could create enduring changes in the syntactic production system of PWA. It is beyond the scope of the current study to determine if the lasting priming effect in PWA is a consequence of implicit error-based learning in the sequencing system (Chang et al., 2006; 2012) or changes in base-level activation for the target message-structure associations (Reitter et al., 2011). However, the findings clearly show that priming effects are persistent and reflect more than a temporary boost of syntactic structures in PWA, extending previous priming studies which have proposed use of structural priming as an intervention strategy for syntactic deficits in aphasia (Cho-Reyes et al., 2016; Lee & Man, 2017; Lee et al., under review a, b). Further, the present results suggest that the dialogue priming paradigm can be employed as a treatment of syntactic processing that approximates conversational interaction, departing from existing treatment approaches (e.g., TUF, Mapping Therapy) involving explicit training of linguistic representations and operations (Rochon et al., 2005; Schwartz et al., 1994; Thompson et al., 2003; 2005).

It is worth noting that PWA failed to show reliable priming effects for datives in both experiments, in contrast with the significant abstract priming effects seen in transitives. Some prior studies with young adults also reported discrepancies between the transitive and dative structures (Bock & Griffin, 2000 for review; Bock, 1986; Bock & Loebell, 1990; Hartsuiker & Kolk, 1998b). The PWA tested in Saffran and Martin (1997; see also Yan et al., 2018) showed priming only in transitives, but not in datives in the experimental testing session, although they showed some increase in use of datives in spontaneous speech in a post-experimental session (cf. Hartsuiker and Kolk; 1998a). The disparity in the priming effects between transitives and datives may be a consequence of prediction error-based learning mechanisms of structural priming wherein unexpected word-orders instantiate greater priming or ‘learning’ in the individual (Chang et al., 2006; 2012; Jaeger & Snider, 2013). Passive sentences are considerably less frequent than active sentences, and PWA would therefore not expect them to occur during comprehension. Moreover, our transitive alternations involved semantically reversible sentences (both agent and theme were animate), which are difficult to produce spontaneously in PWA (Saffran et al., 1980; Cho-Reyes & Thompson, 2010). Thus, our PWA would experience greater prediction errors during comprehension of the passive primes, resulting in a stronger priming effect for transitives. In contrast, because DO sentences are only slightly less frequent than PO sentences, the error between what the individual would predict and what they actually hear is smaller, which in turn might have resulted in non-significant priming for datives in our PWA. Another reason for this discrepancy could be due to greater pragmatic saliency associated with transitive, passive/active alternations compared to dative, PO/DO alternations (Hartsuiker & Kolk, 1998b; see Bock & Griffin, 2000 for other accounts). Because transitive alternations involve change of subjecthood, shifting focus of attention among interlocutors, these alternations may highlight pragmatic aspects of the task to a greater extent than dative alternations. This increased pragmatic saliency might have nicely aligned with the goal-driven interactive nature of our dialogue-like task, encouraging our participants to echo the experimenter’s syntactic choices to a greater extent than in the case of datives. Further research is needed to better test these hypotheses.

In conclusion, while there is increasing interest in using structural priming to facilitate syntactic production in aphasia, the extent to which the mechanisms of structural priming are preserved and enduring remains largely unknown. The present study was a systematic investigation of the mechanisms of lexically independent and lexically-specific priming in a dialogue-like comprehension-to-production task, above and beyond previous structural priming studies in aphasia. A set of important findings were obtained. Our PWA demonstrated preserved comprehension-to-production priming in a dialogue-like task, at least for transitive targets. In Experiment 1, when prime and target were processed consecutively, only abstract priming was preserved. The abstract priming persisted over intervening fillers, indicating that dialogue-based structural priming creates enduring effects in the grammatical encoding system of aphasia, possibly reflecting intact syntactic learning in PWA. Collectively, the current findings indicate that syntactic representations are shared between modalities and remain intact in aphasia and that it may be feasible to use a dialogue-like comprehension-to-production priming as a means to strengthen weakened message-syntax mapping in aphasia.

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Table 1. Language testing results for PWA.

	WAB-R			NAVS						
PWA	AQ (100)	Fluency (10)	AC (10)	VNT (100)	VCT (100)	ASPT (100)	SPPT_C (100)	SPPT_NC (100)	SCT_C (100)	SCT_NC (100)
A1	92.9	9	9.4	91	100	97	100	100	100	100
A2	75.7	4	8.5	86	100	94	73	33	87	93
A3	78.6	6	9.0	96	100	88	60	7	93	100
A4	84.6	6	9.1	100	100	97	93	80	100	93
A5	70.3	8	5.3	80	100	69	13	0	60	33
A6	82.9	6	8.9	86	100	91	47	20	47	60
A7	91.6	9	8.7	73	100	100	100	33	87	100
A8	77.0	6	8.8	50	100	94	80	7	80	60
A9	75.0	8	6.7	77	86	66	20	27	73	47
A10	97.4	9	10.0	96	100	100	100	100	100	100
A11	83.0	5	10.0	97	100	100	100	93	100	100
A12	69.6	5	8.7	73	100	100	13	0	93	27
A13	93.1	9	9.9	95	100	100	100	100	100	100
A14	89.2	8	9.6	95	100	100	87	93	100	93
A15	74.3	4	8.4	79	82	53	60	40	60	60
A16	66.8	4	8.3	55	100	91	93	60	53	27
A17	83.0	6	8.8	64	100	94	80	13	100	80
Mean	81.5	6.6	8.7	82	98	90	72	47	84	75
SD	9.1	1.9	1.2	15	5	14	31	39	19	28

Note: AC = Auditory Comprehension, VNT = Verb Naming Test, VCT = Verb Comprehension Test, ASPT = Argument Structure Production Test, SPPT_C = Sentence Production Priming Test (Canonical), SPPT_NC = Sentence Production Priming Test (Non-canonical), SCT_C = Sentence Comprehension Test (Canonical), SCT_NC = Sentence Comprehension Test (Non-canonical); WAB-R = Western Aphasia Battery-Revised, NAVS = Northwestern Assessment of Verbs and Sentences.

Table 2. PWA's performance on selected lexical-semantic short-term memory subtests of the TALSA. The group means (SDs) are provided for HOA.

	TALSA		
Participant	Category Probe (7)	Synonymy Triplet 3-item (40)	Synonymy Triplet 2-item (40)
A1	3.8	37	40
A2	1.8	32	36
A3	1.8	30	29
A4	4.6	38	39
A5	0.0	27	32
A6	2.7	29	39
A7	n/a	n/a	n/a
A8	4.0	32	40
A9	1.2	27	32
A10	n/a	n/a	n/a
A11	4.3	39	38
A12	2.6	38	35
A13	2.3	39	40
A14	3.9	39	39
A15	1.9	n/a	n/a
A16	3.4	32	37
A17	2.5	27	32
PWA Mean (SD)	2.7 (1.3)	33 (5)	36 (4)
HOA Mean (SD)	6.3 (1.0)	39 (1)	40 (.2)

TALSA = Temple Assessment of Language and Short-Term Memory in Aphasia.

Table 3. A set of example target and prime stimuli used in both experiments. Each target picture can be described in alternating syntactic structures (active/passive for transitive; PO/DO for dative).

Target Structure	Example Stimuli	Condition
Transitive	A horse pulling a girl	Target Transitive Picture
	The tiger is pulling the soldier	Same Verb, Active Prime
	The soldier is being pulled by the tiger	Same Verb, Passive Prime
	The dog is chasing the queen	Different Verb, Active Prime
	The queen is being chased by the dog	Different Verb, Passive Prime
Dative	A nun throwing a mug to a swimmer	Target Dative Picture
	The chef is throwing the gun to the boxer	Same Verb, PO Prime
	The chef is throwing the boxer the gun	Same Verb, DO Prime
	The thief is giving the hat to the priest	Different Verb, PO Prime
	The thief is giving the priest the hat	Different Verb, DO Prime

Table 4. Proportions of 'correct' target responses produced under each prime condition for Experiment 1 and 2.

		Experiment 1		Experiment 2	
Verb	Prime	HOA	PWA	HOA	PWA
Transitive Targets					
Same Verb	Active	100%	77%	100%	80%
	Passive	100%	75%	100%	79%
Different Verb	Active	99%	77%	100%	82%
	Passive	100%	77%	100%	80%
Dative Targets					
Same Verb	PO	100%	85%	99%	88%
	DO	99%	90%	99%	86%
Different Verb	PO	98%	88%	99%	87%
	DO	100%	88%	99%	86%

Table 5. Summary of logistic mixed effects models, Experiment 1.

Predictors	Log-odds Estimate	Std. error	z value	Pr (> | z |)
Transitive Targets: HOA vs. PWA				
(Intercept)	1.10	0.35		
Prime Type	2.25	0.47	4.75	<.0001
Verb	-1.11	0.24	-4.59	<.0001
Group	1.48	0.66	2.24	<.05
Prime Type x Verb	1.62	0.55	2.95	<.01
Prime Type x Group	0.76	0.85	0.89	0.37
Verb x Group	0.26	0.45	0.58	0.56
Prime Type x Verb x Group	-1.73	0.89	-1.93	0.05
Transitive: HOA				
(Intercept)	1.11	0.37		
Prime Type	2.19	0.48	4.55	<.0001
Verb	-1.13	0.26	-4.34	<.0001
Prime Type x Verb	1.56	0.55	2.85	<.01
Transitive: PWA				
(intercept)	2.42	0.49		
Prime Type	2.59	0.64	4.07	<.001
Verb	-0.63	0.38	-1.68	0.09
Prime Type x Verb	0.13	0.71	0.18	0.86
Dative Targets: HOA vs. PWA				
(Intercept)	1.86	0.33		
Prime Type	1.57	0.45	3.48	<.001
Verb	-0.32	0.28	-1.14	0.25
Group	2.00	0.75	2.67	<.01
Prime Type x Verb	0.91	0.53	1.72	0.08
Prime Type x Group	-0.45	0.90	-0.49	0.62
Verb x Group	-0.06	0.60	-0.10	0.92
Prime Type x Verb x Group	-1.97	1.00	-1.97	0.05
Dative: HOA				
(Intercept)	1.85	0.32		
Prime Type	1.54	0.44	3.53	<.001
Verb	-0.32	0.27	-1.20	0.23

Prime Type x Verb	0.89	0.53	1.69	0.09
Dative: PWA				
(intercept)	4.68	1.01		
Prime Type	1.39	1.05	1.33	0.18
Verb	-1.30	0.77	-1.68	0.09
Prime Type x Verb	-1.14	0.97	-1.18	0.24

Table 6. Summary of logistic mixed effects models, Experiment 2.

Predictors	Log-odds Estimate	Std. error	z value	Pr (> | z |)
Transitive Targets: HOA vs. PWA				
(Intercept)	2.46	0.42		
Prime Type	1.13	0.47	2.42	<.05
Verb	-0.12	0.34	-0.35	0.72
Group	0.10	0.73	0.14	0.89
Prime Type x Verb	0.04	0.49	0.09	0.93
Prime Type x Group	0.55	0.71	0.78	0.43
Verb x Group	0.09	0.53	0.16	0.87
Prime Type x Verb x Group	-0.26	0.77	-0.34	0.74
Transitive: HOA				
(Intercept)	2.47	0.42		
Prime Type	0.96	0.41	2.38	<.05
Verb	-0.12	0.33	-0.34	0.73
Prime Type x Verb	0.00	0.48	0.01	0.99
Transitive: PWA				
(intercept)	2.56	0.62		
Prime Type	2.65	0.82	3.21	<.01
Verb	-0.17	0.41	-0.41	0.68
Prime Type x Verb	-0.22	0.62	-0.35	0.73
Dative Targets: HOA vs. PWA				
(Intercept)	2.57	0.43		

Prime Type	0.10	0.45	2.22	<.05
Verb	0.37	0.35	1.05	0.29
Group	1.44	0.90	1.60	0.11
Prime Type x Verb	-0.02	0.5	-0.05	0.96
Prime Type x Group	-1.10	0.72	-1.54	0.12
Verb x Group	-0.59	0.59	-1.01	0.31
Prime Type x Verb x Group	0.05	0.87	0.06	0.95
Dative: HOA				
(Intercept)	2.61	0.45		
Prime Type	1.00	0.39	2.54	<.05
Verb	0.13	0.35	0.38	0.70
Prime Type x Verb	-0.19	0.53	-0.37	0.71
Dative: PWA				
(intercept)	5.10	1.3		
Prime Type	-0.92	0.81	-1.14	0.25
Verb	-1.27	0.61	-2.10	<.05
Prime Type x Verb	0.30	0.70	0.43	0.67

Figure Captions

Figure 1. Experimental set-up, demonstrating a transitive prime-target pair in Experiment 1 (0-lag). Two filler trials intervened between prime and target in Experiment 2 (2-lag).

Figure 2. Priming results (with standard error bars) for transitive (top) and dative (bottom) targets for HOA and PWA in Experiment 1 (0-lag). For transitive targets, increased % active structures produced following active vs. passive primes indicates the priming effect. For dative targets, increased % PO structures produced following PO vs. DO primes indicates the priming effect.

Figure 3. Magnitudes of priming in individual PWA and HOA for Experiment 1. For transitive targets, magnitude of priming corresponds to the difference in proportions of active structures produced between active and passive prime conditions. For dative targets, magnitude of priming corresponds to the difference in proportions of PO structures produced between PO and DO prime conditions.

Figure 4. Priming results (with standard errors) for transitive (top) and dative (bottom) targets for HOA and PWA in Experiment 2 (2-lag). For transitive targets, increased % active structures produced following active vs. passive primes indicates the priming effect. For dative targets, increased % PO structures produced following PO vs. DO primes indicates the priming effect.

Figure 5. Magnitudes of priming in individual PWA and HOA for Experiment 2. For transitive targets, magnitude of priming corresponds to the difference in proportions of active structures produced between active and passive prime conditions. For dative targets, magnitude of priming corresponds to the difference in proportions of PO structures produced between PO and DO prime conditions.