IMPLICITLY PRIMING SENTENCE PRODUCTION IN PERSONS WITH APHASIA USING A COMPREHENSION TASK

by

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ABSTRACT

Background: Structural priming – a tendency to reuse previously encountered sentence structures – has been shown to facilitate production of sentences in persons with aphasia (PWA). However, the task-specific and person-specific factors that modulate the strength of priming effects in PWA remain largely unknown. This study examined (a) if PWA and healthy older adults (HOA) demonstrate improved production of passive sentences following *comprehension* of passive (as opposed to active) prime sentences, (b) whether repeated use of a verb between a prime and target sentence boosts priming effects, and (c) whether individual participants' deficits in syntactic processing modulate degrees of priming effects.

Method: The participants (16 HOA and 13 PWA) completed a comprehension-to-production structural priming task. For prime sentences, they completed a sentence-to-picture matching comprehension task. Then, they described a target action picture, which could be described in an active or passive sentence structure. For half of the prime-target pairs, the verb was repeated to compare the priming effects in the same vs. different verb prime conditions (i.e., lexical boost). To analyze individual variability, we examined if PWA's scores on clinical measures of syntactic comprehension and production were associated with a positive priming effect.

Results: Both HOA and PWA showed increased production of passive sentences following comprehension of passive primes, although the priming effect was reduced for PWA. A significant lexical boost was found in HOA, but not for PWA. Within PWA, individuals with higher scores on clinical measures of syntactic production, but not syntactic comprehension, showed a significant priming effect.

Conclusion: The findings suggest that implicit comprehension-to-production structural priming is preserved in aphasia and that lexically-mediated structural priming may not be critical to effectiveness of structural priming in aphasia. Preliminary results indicate that individuals' syntactic skills in the domain of production may need to be considered when comprehension-to-production priming is used to improve sentence production.

INTRODUCTION

Effective language production relies on implicit processes of mapping a message onto a linguistic form following the conventions of the language (Bock & Ferreira, 2014; Levelt, 1989). Many persons with aphasia (PWA) exhibit deficient mapping, affecting production of a range of sentence structures (Caramazza & Miceli, 1991; Lee, Yoshida, & Thompson, 2015; Saffran, Schwartz & Marin, 1980; Schwartz, Saffran, Bloch & Dell, 1994; Thompson, Faroqi-Shah & Lee, 2015). Utterances requiring a non-canonical mapping between the semantic (e.g., thematic roles) and syntactic (e.g., word order) representations are often impaired in PWA (Kegl, 1995; Menn, 2000; Thompson, Shapiro, Kiran & Sobecks, 2003). In Cho & Thompson (2010), for example, PWA described a set of images containing transitive actions, showing increased errors producing passive sentences. They often produced role-reversal errors between the agent and theme (e.g., *The boy was pushed by the girl* for target *The girl was pushed by the boy*). For intransitive sentences, PWA make more errors producing unaccusative intransitive sentences (e.g., *The glass broke*), as compared to unergative intransitive sentences (e.g., *The man swam*). This is due to the theme noun being mapped to the subject position in unaccusatives, creating more complex mapping (Lee & Thompson, 2004; McAllister, Bachrach, Waters, Michaud & Caplan, 2009).

A group of researchers proposed that PWA struggle with "an impoverished representation" of some linguistic features, with that lack of representation leading to a dearth in production (Caramazza & Zurif, 1976; Friedmann, 2001; Friedmann & Grodzinsky, 1997; Grodzinsky, 1990, pp. 55-62; Hagiwara, 1995). However, these accounts have been largely disproven by multiple comprehension and production studies indicating that linguistic representations remain relatively intact in many PWA. More recent research suggests that inefficient processes of activating and computing linguistic representations underlie the mapping disorder in aphasia and that individuals'

specific cognitive-linguistic profiles may support use of different rehabilitation strategies (Bastiaanse & van Zonneveld, 2005; Kolk, 1995; Lee et al., 2015; Linebarger, Schwartz, Romania, Kohn & Stephans, 2000; Mack, Ji & Thompson 2013; McAllister et al., 2009). However, there are currently only a few theoretically-grounded treatments available to improve sentence production in PWA. These treatments heavily focus on explicit drilling of grammatical rules to re-teach sentence formulation. While some patients show positive outcomes, not all patients benefit from these explicit training of sentence production (Man, Dick, & Lee, 2015; Murray, Ballard & Karcher, 2004). Therefore, there is a critical need to improve intervention options for PWA.

Recently, there has been a growing interest in applying implicit structural priming to PWA as a means of facilitating production of sentence structures that are otherwise difficult to produce for them (e.g., Cho-Reyes, Mack, & Thompson, 2016; Lee & Man, 2017; Man, Meehan, Martin, Branigan & Lee, 2019; Yan, Martin, & Slevc, 2018). Emerging evidence suggests that structural priming holds a potential to be used as a clinical tool for aphasia rehabilitation (see the 'Structural priming in persons with aphasia' section below). However, the current evidence is quite preliminary, and little is known about if and how different task-specific and person-specific factors modulate strength of priming effects in aphasia. This thesis investigates the effect of comprehension-based structural priming to facilitate production of passive sentences in PWA.

Structural priming in healthy adults

Structural priming is a tendency to more easily comprehend or produce a sentence with the same grammatical structure as a previously presented sentence. It occurs ubiquitously in different structures and language tasks in healthy adults (Bock, 1986; Bock, Dell, Chang & Onishi, 2007; Branigan & McLean, 2016; Chang, Dell, Bock & Griffin, 2000; Pickering, Martin & Ferreira, 2008). For example, hearing or reading a passive sentence (e.g., *The man was chased by a dog*)

will increase the chance that someone produces a passive sentence to describe a new transitive event (e.g., *The woman was kissed by a boy*) rather than an active sentence. Notably, structural priming is thought to be largely *implicit* in nature. That is, the structural repetition does not require overt instruction on sentence structures to use, or even the ability to explicitly recall previous sentences. This was first shown by Bock (1986), wherein participants were asked to identify whether an image had been presented to them in a previous list, repeat descriptive sentences given to them by the test administrator, and verbally describe a new picture proceeding this repetition. Though the participants were only asked to remember the content of the images (e.g., nouns and actions), with no overt nod to sentence structure, they still demonstrated structural priming. Further, Ferreira, Bock, Wilson, & Cohen (2008)'s study showed significant structural priming in production even in participants with amnesia whose explicit memory was impaired, suggesting that explicit knowledge of sentence structure is unnecessary for priming to occur.

More recently, researchers have suggested that priming effects are a consequence of language learning that generates spreading and enduring changes within the language processing system, rather than transient activation or strategic repetition (Branigan & Pickering, 2017; Chang, Dell & Bock, 2006; Griffin & Bock, 2000; Jaeger & Snider, 2013; Pickering & Branigan, 1998; Reitter, Keller & Moore, 2011). In support of this view, it has been found that priming is both cumulative and persisting. For example, the overall odds of passive sentence production rise with the number of trials that a participant experiences within a session, showing that priming creates a cumulative change in participants (Bernolet, Collina & Hartsuiker, 2016; Branigan & McLean, 2016). Priming effects remain significant over a set of intervening linguistic materials (fillers) between a prime and a target or across multiple sessions, suggesting that structural priming creates long-term changes in language users (Griffin & Bock, 2000; Hartsuiker, Bernolet, Schoonbaert,

Speybroeck & Vanderelst, 2008). The theory of priming as implicit learning is also supported by the "inverse frequency effect" in which lower-frequency structures may experience more significant levels of priming than high-frequency structures (Scheepers, 2003; Snider & Jaeger, 2009).

Researchers have studied various factors that account for structural priming effects. One prevalent cognitive model suggests that structural priming is caused by prediction-error based implicit learning during incremental *comprehension* of the prime sentence (Chang et al., 2006; 2012; Griffin & Bock, 2000; Jaeger & Snider, 2013). As the language user comprehends a prime sentence, they make predictions about the upcoming word order. When that prediction is violated, such as a passive-transitive sentence being encountered when an active-transitive was anticipated, the discrepancy ('error') creates an adjustment in the syntactic system that is assumed to be shared between the comprehension and production modalities. This in turn increases the probability of using the primed structure more frequently in the future. Thus, in this model, comprehension of prime sentences is sufficient to significantly bias sentence production. In support of this proposal, existing studies show comparable priming effects regardless of the mode of prime sentence processing, whether it be a comprehension-to-comprehension, comprehension-to-production, or production-to-production language task (Bock, 1986; Bock et al., 2007; Ferreira et al., 2008; Thothathiri & Snedeker, 2007; Traxler, Tooley, & Pickering, 2014). Additionally, many studies with young adults show that simply hearing their conversational partner's utterances is sufficient to change the participant's syntactic choices in production (Branigan et al., 2000; Branigan & McLean, 2016). However, it has yet to be tested if these patterns hold true for PWA.

Another well-established factor is the 'lexical boost effect,' wherein lexical overlap between a prime and a target sentence enhances priming effects. Earlier studies have assumed that

structural priming occurs not at the lexical level, but primarily at the level of abstract syntactic phrases (Bock, 1986; 1989). More recent findings, however, show that structural priming can be lexically-mediated, spreading across different levels of linguistic representations. Specifically, lexical-semantic boost on priming has been reported in multiple studies (Cleland & Pickering, 2003; Hartsuiker et al., 2008; Mahowald, James, Futrell & Gibson, 2016; Pickering & Branigan, 1998). According to Mahowald et al. (2016)'s meta-analysis of priming studies, structures that typically occurred at chance (50%) occurred 77% of the time when primed and given lexical overlap, compared to 63% when there was priming without lexical repetition. This suggests that when there is a lexical item repeated between a prime and target, the shared lexical information increases spreading activation to the associated structural information, leading to increased priming (Pickering & Branigan, 1998; Reitter et. al., 2011).

Structural priming in persons with aphasia

There is a rapidly increasing evidence showing that structural priming holds potential to be used as a clinical tool for PWA. Earlier studies have largely focused on analyzing immediate priming effects, demonstrating that PWA are able to produce more complex sentences such as passives or datives immediately after a prime (Saffran & Martin, 1997; Hartsuiker & Kolk, 1998; Rossi, 2015; Verryet et al., 2013). More recent studies have begun to focus on longer-term, persistent priming effects in PWA (e.g., Cho-Reyes et al., 2016; Man et al., 2019; Lee & Man, 2017; Lee, Man, Ferreira, & Gruberg, 2019). For example, in Cho-Reyes et al. (2016)'s experiment with agrammatic PWA, participants repeated prime sentences that they heard and saw in writing before being presented with a set of written words that they then combined into a spoken sentence. PWA showed increased production of primed grammatical structures — prepositional object (PO) and double object (DO) dative structures — with a priming effect comparable to the healthy control

group. Notably, priming was not only immediately facilitated but also remained present over a lag of 4 intervening fillers for both groups.

Even longer-term persistence was recorded in Lee & Man (2017)'s case study, wherein their participant received twelve priming sessions for PO sentences, showing lasting effects on production of both trained and untrained PO sentences up to four weeks afterwards. Their patient also produced more sentences and verbs in spontaneous speech production. These lasting and generalized results would suggest the presence of priming-induced learning, an adaptation to PWA's internal language-learning mechanisms, as opposed to being a case of explicit, strategic repetition. However, little systematic evidence is available about how different task-specific and person-specific factors modulate strength of priming effects in aphasia. Without a clear delineation of these questions, an evidence-based and effective application of a structural priming paradigm in aphasia rehabilitation would be limited. This thesis examines three questions, addressing some of these gaps in the literature.

The first question to be examined is whether comprehension-to-production priming is effective in PWA, as hypothesized by the prediction-error based implicit learning theories of structural priming (Chang et al., 2006; 2012; Jaeger & Snider, 2013). Most structural priming studies with PWA used production-to-production priming, wherein participants were asked to overtly attend to and produce the prime sentence (Saffran & Martin, 1997; Hartsuiker & Kolk, 1998; Cho-Reyes et al., 2016; Lee & Man, 2017; Yan et al., 2018). For example, in Yan et al. (2018), a PWA may hear the prime sentence, repeat it, and see it written out to verify their correct repetition. Although the PWA in these studies were not explicitly told to use the same sentence structure in their production as the prime sentence they produced, the increased depth of encoding of primes may have encouraged PWA to rely on explicit rather than implicit memory. Thus, it is

still unclear whether production-to-production structural priming truly reflects implicit learning in PWA.

One way to better understand if *implicit* learning is taking place is to analyze whether comprehension-based priming is effective in PWA. In fact, there are currently only two studies that used comprehension-to-production priming with PWA (Lee et al., 2019; Man et al., 2019). Both studies used a dialogue-like picture matching task, where participants took turns to describe pictures with an interlocutor. In Lee et al. (2019), PWA failed to show reliable priming effects when they heard their partner's sentences (primes) but did show priming after orally repeating their partner's sentences. Man et al. (2019), however, found that simply hearing their partner's choice of sentence structures significantly primed PWA to use the same structures in their own production of target sentences.

Secondly, the role of lexical overlap on structural priming in PWA has not been extensively researched. There are only two studies that have set out to examine whether verb overlap between prime and target sentences boosts priming effects, yielding mixed findings (Yan et al., 2018; Man et al. 2019). In the study by Yan et al. (2018), the effects of lexically-mediated priming on sentence production were clear, with PWA showing greater production of passive sentences when the verb was repeated between primes and targets, compared to when there was no verb overlap. On the other hand, in Man et al. (2019), the PWA, prompted to describe pictures in a dialogue format with an interlocutor, showed no lexical boost. Participants showed equal degrees of priming in the same and different verb prime conditions. These inconsistent findings show that there is a need to further examine if lexical overlap between prime and target can enhance structural priming in PWA.

A third question is the exploratory analysis of individual variability in priming effects in PWA. Person-level factors and how they contribute to implicit priming tasks has received little

attention in the literature. Cho-Reyes et al. (2016), in their examination of oral repetition-based priming task with a group of participants with Broca's (agrammatic) aphasia, found that individuals with lower scores on a sentence construction test showed larger priming effects. Lee (2020), on the other hand, had inverse findings. The study examined how participants with varying aphasia types produced active versus passive sentences in response to different lexical (agent, theme) primes that they heard. It was found that the PWA with higher scores on syntactic processing (both comprehension and production) tests showed greater priming effects compared to those with lower scores on the same tests. This thesis tests whether individual PWA's scores on clinical tests of syntactic production and comprehension are associated with different degrees of priming. Better understanding of how different person-level factors modulate priming effects may allow a better matching of individuals to different priming tasks in intervention.

The current study

The purpose of the current study is to examine the effects of comprehension-based structural priming on production of passive sentences in HOA and PWA. The participants described a transitive action picture in a sentence (target) following comprehension of either an active or passive prime sentence. An auditory sentence-to-picture matching comprehension task was used for prime sentences. We measured if participants would produce passive sentences more frequently than active sentences after comprehension of a passive vs. active prime. This study is part of a larger study examining the effects of various prime types on off-line and on-line (eyetracking) sentence production in aphasia. This thesis reports on the data examining the effect of structural priming on off-line sentence production. The following three research questions were examined:

a. Do HOA and PWA show increased production of passive sentences after comprehension of passive vs. active prime sentences? It was predicted that if a comprehension-to-production priming is effective, HOA and PWA will show increased production of passive sentences after a picture-matching task of a passive vs. an active prime sentence.

b. Do HOA and PWA show a lexical boost effect? To test this question, the verb was repeated for half of the prime-target pairs, while different verbs were used for the other half pairs. It was predicted that if lexical overlap boosts priming effects, participants will show an increased priming effect in the same verb compared to the different verb priming condition.

c. Do individual PWA's syntactic processing skills (as measured by clinical diagnostic assessments) modulate degrees of priming effects in a comprehension-to-production task? To address this exploratory question, PWA's scores on the non-canonical sentence stimuli of the Sentence Comprehension Test (SCT) and Sentence Priming Production Test (SPPT) of the Northwestern Assessment of Verbs and Sentences (NAVS; Thompson, 2011) were used. Based on a median-split, PWA were assigned into high vs. low syntax groups. It was predicted that if individual differences in syntactic processing skills is an important factor in predicting degrees of structural priming effects, the subgroups of PWA will show differences in priming effects.

METHODS

Participants

The experiment consisted of a control and an experimental group. Sixteen healthy older adults (HOA; 9 females, 7 males; age M (SD) = 60.8 (8.7); education years M (SD) = 17.25 (1.6)) who were native speakers of English, with no reported history of cognitive/neurological or language disorders acted as the controls. To confirm their eligibility to participate in the study, all HOAs underwent a cognitive-linguistic screening using the Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, 2001). Their composite scores fell within normal age-defined limits (Clinical Severity Ratings ranged from 3.6-4.0/4.0), indicating that they have no significant deficits within the five cognitive domains of attention, memory, executive functioning, language, and visuospatial skills.

A total of fifteen English-speaking PWA were tested as the experimental group (8 females, 7 males; age mean = 66.6, SD = 12.8). To be included in the study, they had to have a diagnosis of aphasia resulting from a left hemisphere stroke at least 6 months prior to study participation (mean post-stroke onset time in months M (SD) = 60.3 (40.1)). They reported no history of neurological or psychological conditions prior to stroke. Their aphasia severity and profiles were determined based on a set of language tests, including the Western Aphasia Battery-Revised (WAB-R; Kertesz, 2007) and the Northwestern Assessment of Verbs and Sentences (NAVS; Thompson, 2011). The PWA demonstrated mild-to-moderate aphasia secondary to a left-sided stroke, as indicated by WAB-R aphasia quotient scores. They showed relatively preserved skills in comprehension of single words and simple sentences, although they showed more difficulty comprehending complex, non-canonical, sentences on the NAVS. They had to demonstrate a preserved ability to produce some single words and simple sentences to participate in the task.

Additionally, all participants reported normal or corrected-to-normal vision and passed a hearing screening at 500Hz, 1000HZ, and 2000Hz at 40 dB in at least one ear. Informed consent was obtained from all participants prior to testing, and the participants were compensated for their time.

Table 1. Language Test Background. PWA's performance on language tests.

	Western Aphasia Battery- Revised WAB-R					Northwestern Assessment of Verbs and Sentences NAVS						
PWA	AQ (100)	AC (10)	Fluency (10)	Naming (10)	Repetition (10)	VNT (100)	VCT (100)	ASPT (100)	SPPT_C (100)	SPPT_NC (100)	SCT_C (100)	SCT_NC (100)
A1	69.6	9	5	7.7	4.4	72.7	100	100	13.3	0	93.3	26.7
A2	84.6	9	6	9.2	9	100	100	97	93	80	100	93
A3**	66.8	7	4	5.8	8.3	54.5	100	90.6	93.3	60	53.3	26.7
A4	83	9	5	8.3	9.2	97	100	100	100	93	100	100
A5	77	9	6	7.3	7.4	50	100	93.8	80	6.7	80	60
A6**	70.3	9	8	6.9	6	80	100	68.8	13.3	0	60	33.3
A7	93.1	10	9	9.1	8.6	95.5	100	100	100	100	100	100
A8	96.2	10	9	9.7	9.4	100	100	100	100	100	100	100
A9	85	9	8	6.7	9.5	95	100	100	93.3	80	80	73
A10	73	8	4	6	10	13.6	90.9	56.3	53.3	60	86.7	80
A11	87.7	9	8	8.9	8.4	83	100	93.8	100	67.7	93.3	86.7
A12	94.4	10	9	10	9	100	100	100	100	3.3	100	100
A13	96.2	10	9	9.7	9.4	100	100	100	100	100	100	80
A14	75.2	8	6	8.4	6.7	81.8	95.5	69.8	33.3	20	60	53.3
A15	86.7	9	8	6.8	10	81.8	100	96.9	100	100	93.3	93.3
Mean	82.6	9	7	8	8.3	80.3	99.1	91.1	78.2	58	86.7	73.7
SD	9.7	0.82	1.80	1.35	1.53	23.63	2.46	13.68	31.68	39.28	15.96	26.36

Note: (**) =excluded from data analysis due to poor performance on the experimental task (see results section).WAB-R =Western Aphasia Battery-Revised; AQ = Aphasia Quotient; AC = Auditory Comprehension; NAVS = Northwestern Assessment of Verbs and Sentences; VNT = Verb Naming Test; VCT = Verb Comprehension Test; ASPT = Argument Structure Production Test; SPPT_C = Sentence Priming Production Test - Canonical Sentences; SPPT_NC = Sentence Priming Production Test- Noncanonical Sentences; SCT_C = Sentence Comprehension Test- Canonical Sentences; SCT_NC = Sentence Comprehension Test- Noncanonical Sentences

Stimuli

Twelve transitive action verbs (e.g., *chase, pull, push*) were selected. These verbs were selected based on the length (1-2 syllables) and log lemma frequency (mean frequency = 1.536, SD = 0.555; (CELEX; Kerkman, Piepenbrock, Baayen, & van Rijn, 1995). In addition, a set of 33 animate nouns (e.g., *chef, dog*) were selected (mean frequency = 0.455, SD = 0.80) (CELEX; Kerkman et al., 1995). Each noun appeared, at most, six times (mean frequency of usage = 3) within the target stimuli, with an overall equal distribution across conditions.

These nouns and verbs were paired to create a total of 96 sentences, including prime and target sentences, distributed among four experimental lists (see below for details). Each list consisted of 24 prime sentences and 24 target sentences. On each list, the verbs occurred twice in prime sentences and twice in target sentences. These primes and targets were paired to avoid phonological and semantic overlap between the actors in each sentence. The nouns within the prime and target stimuli were balanced to ensure that none of them were disproportionately used in the agent or theme position.

Corresponding black-and-white line drawings were created for sentence stimuli. The names of the agent and theme characters (e.g., *dog, rabbit*) were provided in writing to minimize the influence of word-retrieval deficits on sentence production in PWA, as shown in Figure 1. Within each picture, the size and visual saliency of the agent and theme characters were matched whenever possible.

For each list, there were 24 target pictures and 24 prime pictures. Additionally, 24 role-reversal pictures were created to go along with the comprehension prime images in a picture-matching task (e.g., *The dog chases the rabbit/ The rabbit chases the dog*). For half of the pictures, the agent appeared on the left side, and it appeared on the right side for the other half to keep participants from using the agent-first strategy. Target pictures were normed with a group of 10

healthy colleague-aged speakers. All stimuli elicited the preferred target responses at least 97% of the time.

In addition, 92 black-and-white filler sentences and their corresponding images were prepared. The filler items consisted of sentences with a predicate (e.g., *There is a balloon*) or an intransitive structure (e.g., *The dog howls*). The fillers were presented only as comprehension items in a picture-matching task. Each filler sentence was accompanied by two images, one target image and one distractor. Two filler trials with non-transitive sentences were embedded between experimental trials.

Design

This experiment employed a mixed design with prime (active vs. passive) type and verb overlap (same vs. different verb) being within-subject factors and the group being the between-subject factor. Each target picture was elicited under four different prime conditions. For example, the single target picture of *bear pull solider* was elicited by a prime in both active and passive grammatical structure, with each prime condition paired with one overlapping verb and one different verb, as shown below:

a. *active same verb prime:* The clown pulls the dog.
b. *passive* same verb *prime*: The dog is pulled by the clown.
c. *active different verb prime*: The girl weighs the pig.
d. *passive different verb prime*: The pig is weighed by the girl.

The conditions listed above were presented in four lists. Each target was elicited only once in each list. For instance, example (a) is on List 1, example (b) is on List 2, etc. Half of the prime-target pairs in each list had same verb, and the other half had different verbs. Each list included four blocks containing twelve experimental trials, encompassing forty-eight experimental trials

overall. The order of the trials within the blocks was pseudo-randomized so that no more than two trials were presented consecutively from the same prime condition in each list. Each participant received only one list, with the order of list assignment counterbalanced across participants.

Task & procedure

Participants were seated in front of the stimulus display computer monitor. For comprehension primes, two images and a sentence corresponding to the correct target were presented, accompanied by pre-recorded audio reading the sentence aloud (Figure 1). Participants were asked to press a corresponding key on the keyboard to indicate their picture choice to move forward. For target sentence elicitation, a *Your Turn* screen appeared preceding a centered, black fixation cross. Then, a target picture was presented with a pure tone played simultaneously. Next, the target image was displayed. The participants then produced a sentence describing what is happening in the picture. Participants proceeded through the fillers and trials at their own pace, with the experiment taking approximately 40 minutes to an hour. Their eye data were also recorded during the picture description; however, this thesis reports off-line production data only.

Before taking part in the experimental task, participants were familiarized with the experimental nouns and verbs as singletons to minimize potential word retrieval difficulties in PWA. Nouns were presented as a printed word above the corresponding black-and-white picture. Verbs were presented as a single printed word. Participants were asked to verbally read the word, with feedback being provided for errors during this time.

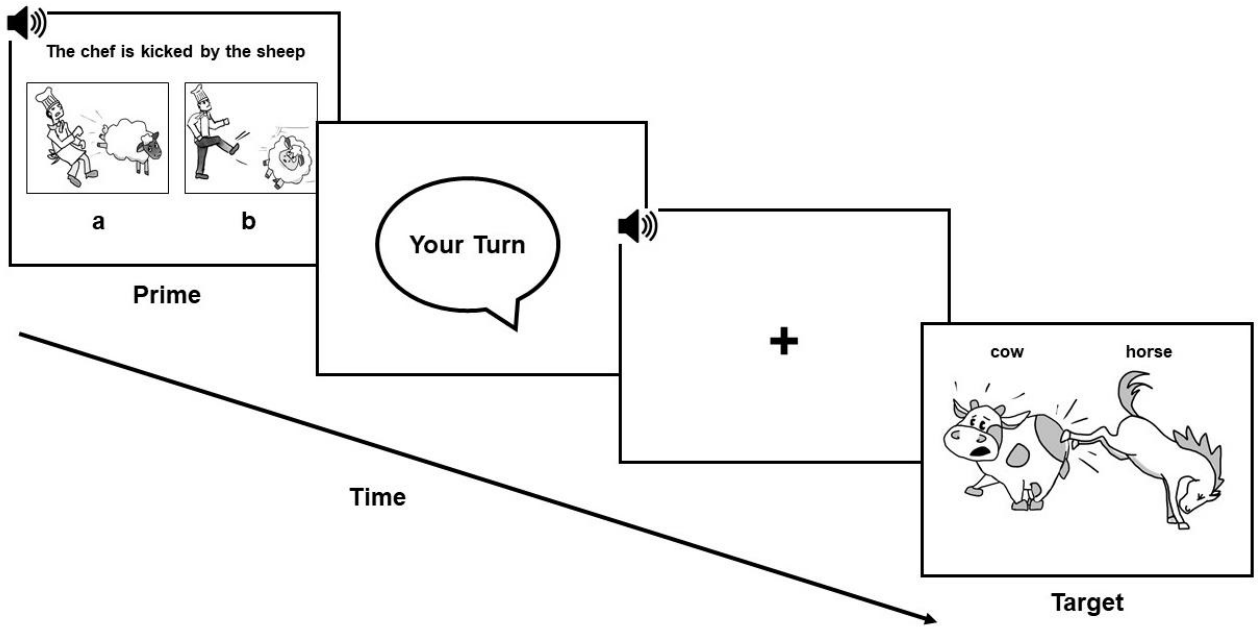

Figure 1. , Experimental Trial. An example of an experimental trial for the same verb, passive prime condition.

Data analysis

Accuracy of comprehension of prime sentences: Using a binary scoring system (correct = 1, incorrect= 0), comprehension primes were scored as correct if the participant chose the appropriate image (a or b) corresponding to the sentence.

Analysis of offline sentence production responses: For the trials in which prime sentences were successfully comprehended, accuracy of the target responses was analyzed. The responses had to be active transitive or passive transitive in structure; they were otherwise excluded from analysis as an incorrect response. For an active response to be scored as correct, it had to include both target nouns and the verb in an agent-verb-theme order. For a passive response to be scored as correct, the target nouns and verb had to be produced in a theme-verb-agent order, with correct verbal morphology consisting of the auxiliary verb and past participle form of the main verb (e.g., *was pushed*), followed by a 'by' prepositional phrase (e.g., *by the man*).

For the HOA and PWA groups, variations in verb inflection (e.g., *punch, punches, punched, is punching*) and substitution with synonyms (e.g., *chef/cook, hit/punch*) were accepted. For PWA, omission of an auxiliary verb (e.g., *the girl lifted by the father*), omission of articles, and intelligible phonemic paraphasic errors were accepted as correct responses. In instances of self-correction or multiple attempts for both groups, the first sentential response, consisting of at least the subject noun and a verb phrase, was scored.

Each correctly produced sentence response was coded for its structure (passive =1, active =0) to analyze priming effects. Increased production of passive responses following comprehension of passive prime sentences compared to active prime sentences was considered as a significant priming effect. This binary variable was entered into logistic mixed-effects models for statistical analysis. To test priming effects, the proportions of passive responses over all correct (active + passive) responses under the passive vs. active prime conditions for each participant was measured.

Error analysis: All incorrect productions from PWA were analyzed to determine the types of errors that occurred. Error analysis was not conduced for HOA, due to their high production accuracy. The following error types were determined, with example error productions taken from the target sentence *The dog chases the mailman*:

- **Non-target structure:** a grammatically correct utterance that does not use one of the alternating target transitive structures. Example: *The mailman runs away from the dog.*
- **Non-sentence response:** inclusion of noun(s) in an utterance but no lexical verb. Example: *The mailman and dog.*
- **Role-reversal:** thematic roles are reversed in the correct structure using the correct target action. Example: *The mailman chases the dog.*

- **Argument structure**: sentences with omitted or incorrect production of arguments. Example: *The dog chased.*
- **Lexical:** substitution with incorrect noun and/or verb, i.e., not accepted synonyms or paraphasias. Production of neologistic paraphasias. Example: *The dog pushed the mailman.*
- **Multiple Errors:** utterance with more than one of the above errors. Example: *The cat chased.*

Statistical analysis

To compare priming effects, logistic mixed-effect regression models were used (Bates, Maechler, Bolker & Walker, 2014). Proportions of passive sentences produced were compared between priming conditions. For a model comparing the two groups, prime type, verb type, and group were entered as a fixed-factors. For a within-group model, prime type and verb type were used as fixed factors. Both by-item and by-participant random slopes and intercepts were included for all main effects in the models.

To test whether individuals' scores on clinical tests of syntactic comprehension and production affects degrees of structural priming effects in PWA, we used the participants' scores on the non-canonical sentence stimuli of the Sentence Comprehension Test (SCT) and Sentence Priming Production Test (SPPT) of the NAVS. For each test, using a median-based split, PWA were assigned into a high vs. low performance group. Then, a set of Wilcoxon signed rank tests were used to compare proportions of passive responses within each group, with the alpha-level corrected for multiple comparisons (.05/2 = .025). Effect sizes are also computed, using Cohen's *d* (Cohen, 1992).

RESULTS

Priming results

To analyze priming effects, we excluded the trials where participants failed to correctly select a matching picture during comprehension of prime sentences or the trials where they produced one of the alternating (active/passive) structures during target picture description. HOA showed an almost perfect accuracy in comprehension primes (range 99-100%). Out of these trials, they produced either an active or passive target sentence in 94% of the time, yielding a total of 724/757 analyzable responses for priming effects. For PWA, data from 2 participants (A3, A6) were excluded because they did not produce any analyzable data in at least one of the priming conditions, resulting in a total of 8% and 21% analyzable trials only, respectively. For the remaining 13 PWA, accuracies in comprehension of prime sentences ranged from 71% to 100% (mean 91%). Out of these correctly comprehended prime trials, they produced either an active or passive target sentence on an average of 69% (430/566) of the trials (range 42%-92%).

The priming effects are shown in Figure 2, comparing production of passive sentences across different prime conditions for each participant group. The results of the statistical analyses are summarized in Table 2. A logistic mixed-effects regression model comparing the two groups revealed a main effect of prime type, indicating participants in general produced more passive sentences following comprehension of passive than active prime sentences. The interaction between prime and verb type was significant, indicating greater priming for the same vs. different verb conditions. Importantly, the 3-way interaction between prime, verb, and group was also significant.

A within-group model for HOA revealed a significant effect of prime and a significant interaction between prime and verb type. That is, HOA showed a larger priming effect in the same,

compared to the different verb condition, indicating a significant lexical boost effect. The model for PWA revealed a significant effect of prime type. They produced reliably more passive sentences after completing picture matching for passive compared to active prime sentences. The effect of verb type was not reliable. However, different from HOA, the interaction between prime type and verb type was not significant, indicating PWA did not show a lexical boost effect on priming.

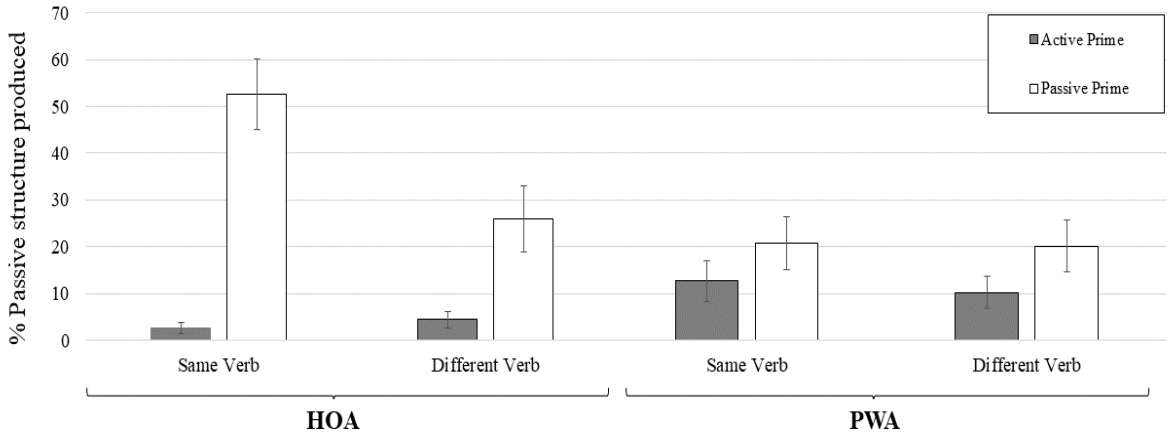

Figure 2. Priming Effects. Priming effects on the production of passive target sentences.

Table 2. Statistical Results for Priming Effects. Summary of logistic mixed-effects models, priming effects.

	Estimate	SE	*Z*	Pr (>|*z*|)
HOA vs. PWA				
(intercept)	-3.5515	0.5135		
Prime	2.0797	0.5039	4.128	<.0001
Verb	-0.7261	0.6836	-1.062	.288
Group	1.0243	0.6944	1.475	.140
Prime x Verb	2.3112	0.6885	3.357	<.001
Prime x Group	-0.9404	0.6976	-1.348	.177
Verb x Group	0.4985	0.8767	0.569	.569
Prime x Verb x Group	-2.3572	0.9260	-2.546	.010
HOA				
(intercept)	-4.8557	0.9141		
Prime	3.0442	0.7776	3.915	<.0001
Verb	-0.4973	0.9855	-0.505	.613
Prime x Verb	2.4137	0.9034	2.672	<.01
PWA				
(intercept)	-2.75298	0.64466		
Prime	1.35840	0.61266	2.217	<.05
Verb	0.06871	0.56346	0.122	.902
Prime x Verb	-0.27386	0.63646	-0.430	.667

Error analysis results

Production errors for PWA were tallied for prevalence of error type under each prime condition. PWA produced a total of 220 incorrect utterances. Of these incorrect productions, 112 errors occurred under active prime condition and 108 errors occurred under passive prime condition, indicating no significant impact of passive vs. active prime condition on overall number of errors. In terms of different error types, use of non-target structures and lexical errors were the two most dominant errors in both passive and active prime conditions.

Table 3. Error Analysis: Percent of errors produced (with the number of errors) by PWA in active vs. passive prime conditions.

Error Types	Overall	Active Prime	Passive Prime
Non-target structure	**29.09%** (64/220)	**26.79%** (30/112)	**31.48%** (34/108)
Non-sentence response	**4.09%** (9/220)	**3.57%** (4/112)	**4.63%** (5/108)
Role reversal	**7.72%** (17/220)	**7.14%** (8/112)	**8.33%** (9/108)
Argument structure	**10.45%** (23/220)	**11.61%** (13/112)	**9.25%** (10/108)
Lexical	**35.45%** (78/220)	**41.07%** (46/112)	**29.63%** (32/108)
Multiple errors	**13.18%** (29/220)	**9.82%** (11/112)	**16.66%** (18/108)
Total	**100%** (220)	**100%** (112)	**100%** (108)

Analysis of individual differences in priming effects

Figure 3 compares priming effects as an effect of PWA's scores on syntactic processing tests. The scores obtained from the PWA on the non-canonical sentence stimuli of the SCT and SPPT of the NAVS were binarized as "high" vs. "low" scores, using a median spit. Because PWA did not show a significant lexical boost effect, priming results were combined between the same and different verb conditions for the current analysis. For SCT, 6 and 7 PWA were assigned into low vs. high SCT groups, respectively. For SPPT, 5 and 8 PWA were assigned into low vs. high SPPT groups, respectively. For SCT scores, neither low SCT nor high SCT group showed a significant priming effect, Wilcoxon Z = -1.826, p = .068 for low SCT group; Z = -1.014, p = .310 for high SCT group. Both groups showed comparable medium effect sizes (Cohen's d's= 0.74 vs. 0.62; Cohen, 1992). For the production (SPPT) scores, the low SPPT group did not show a significant priming effect, Z = .000, p = 1.000. However, the high SPPT group showed a significant

priming effect, Z = -2.240, p = .025. Similarly, effect size analyzes revealed a large priming effect for the high SPPT group (d = 1.26) but a non-significant effect size for the low SPPT group (d = 0.10).

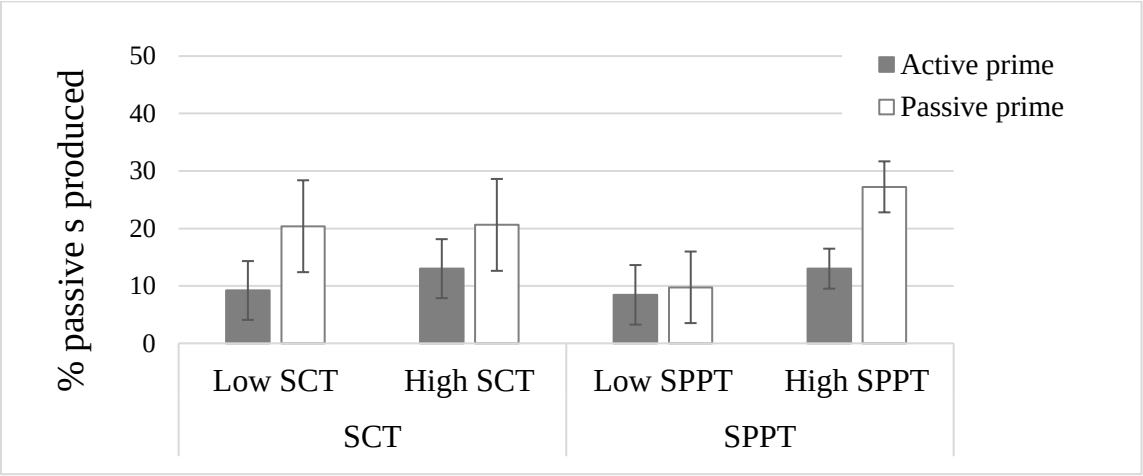

Figure 3. Priming and Syntax Scores. Priming effects as an effect of PWA's scores on syntax processing tests (SCT = Sentence Comprehension Test; SPPT=Sentence Priming Production Test; Error bars = standard errors).

DISCUSSION

Our HOA showed a robust priming effect as well as a lexical boost effect, attesting to the effectiveness of the current comprehension-to-production priming task for healthy adults. They produced an average of 21% more passive sentences after comprehending passive versus active prime sentences for the different verb condition and an average of 50% priming for the same verb condition (creating a mean of 29% lexical boost effect). These priming effects are comparable with previous studies that examined priming on passive sentences in older adults using a dialogue-based comprehension-to-production priming task (Hardy, Messenger, & Maylor, 2017; Man et al., 2019) or production-to-production priming task (Heyslaar, Wheeldon, & Segeart, 2020). For example, Man et al. (2019) showed 25% vs. 47% priming effects in the different and same verb primes, respectively. Similarly, the HOA tested in Hardy et al. (2017) showed a 21.6% lexical boost effect. These findings of significant priming and lexical boost effects seen in our HOA are also consistent with studies using young adult participants taking part in various priming tasks (Cleland & Pickering, 2003; Hartsuiker et al., 2008, Mahowald et al. 2016; Pickering & Branigan, 1998). Taken together, the results from our HOA suggest that comprehension-based priming effectively changes sentence production in older adults, in line with the prediction-error based models of structural priming (Chang et al., 2006; 2012). In addition, the findings suggest that the cognitive mechanisms underlying both abstract structural and lexically-mediated priming remain preserved in healthy aging.

The results from PWA showed a significant priming effect, as evidenced by overall increased production of passive sentences following comprehension of passive vs. active primes, although this effect was reduced compared to HOA. This finding is consistent with Man et al. (2019), in which PWA showed increased production of passive sentences after hearing their

interlocutor's passive vs. active sentences. These findings indicate that a comprehension-based priming task can significantly modulate sentence production in PWA, although the effect is not as strong as seen in healthy older adults. This also aligns with the implicit learning model and suggests that the ability to implicitly re-use previously comprehended sentence structure is preserved in PWA. The presence of significant priming effects seen in our PWA is also in line with theories hypothesizing that mapping deficits seen in aphasia are due to inefficient information processing, rather than a loss of linguistic representation (de Roo, Kolk, & Hofstede, 2003; Haarmann & Kolk, 1991; Lee et al., 2015; Linebarger et al., 2000).

However, unlike HOA, no significant lexical boost effect was observed in our PWA. Repetition of the same verb between prime and target sentences did not reliably enhance the priming effect in PWA. This lack of a reliable lexical boost effect in our PWA is consistent with the findings of Man et al. (2019), but it is inconsistent with those of Yan et al. (2018). This difference may be attributable to the different priming tasks used between the two studies. Both the current study and Man et al. (2019) used comprehension-based priming. On the other hand, in Yan et al. (2018)'s study, their PWA heard the prime sentence, repeated it, and then read a written version of the prime sentence to verify if their repetition was correct. Thus, this increased attention to prime sentences may have recruited different cognitive processes (such as explicit memory for lexical items) during the priming task, increasing the lexical boost effect (Reitter et al., 2011; Chang et al., 2012). Further research is needed to better understand how the depth of attention and cognitive control associated with different priming tasks interact with lexically-mediated and abstract structural priming effects. Nonetheless, these findings are in line with the previous studies suggesting that the underlying mechanisms behind abstract structural priming and lexical boost are separate and can be dissociated from each other, as was hypothesized by Hartsuiker et al. (2008)

and Ferreira and Bock (2006), who associated the lexical boost effect with explicit memory retrieval. Ferreira et al. (2008) indicated that explicit memory skills are not needed to facilitate abstract structural priming, which may explain why PWA in this study showed abstract structural priming but no lexical boost under the current conditions of the task.

Lastly, it is worth discussing the effects of individual differences in syntactic processing skills on the current findings. Our exploratory analysis revealed that PWA with greater syntactic production abilities showed a more robust priming effect than PWA with relatively more impaired syntactic production. This is partially consistent with Lee (2020)'s findings, wherein individuals with stronger syntactic processing skills in both comprehension and production tests were able to show increased production of passive or active sentences in response to varying lexical (agent or theme noun) availability. However, the findings are at odds with those of Cho-Reyes et al. (2016), who showed PWA with lower scores on sentence construction showed increased priming. Direct comparisons are difficult to make between these studies. Cho-Reyes et al. (2016) used a repetition-based, production-to-production task and included only individuals with agrammatic Broca's aphasia. It is possible that in a less structured priming task, such as our comprehension-based task, a certain degree of preserved syntactic ability, more specifically in the production modality, is needed for implicit syntactic learning to occur in PWA. The current preliminary results also indicate that individuals' syntactic skills in the domain of production may need to be considered when comprehension-to-production priming is used to improve sentence production.

However, we interpret these findings on individual differences with caution given the small sample sizes and the preliminary nature of the analyses. More research is necessary to consider other person-level factors that were not accounted for in this current study, such as individual strengths and deficits in implicit vs. explicit memory skills. Performance on a serial reaction time

task, for example, has been shown to predict priming effects in both children and older adults, indicating implicit-memory based statistical learning can be a critical person-level contributor to structural priming (Kidd, 2012; Heyslaar et al., 2020). It would also be beneficial to analyze online (e.g., eyetracking) priming results for our participants to gain a more in-depth understanding of how the current priming task affects real-time sentence production processes in PWA as a group and at the individual level.

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