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On the Parity of Structural Persistence in Language Production and Comprehension

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Abstract

Structural priming creates structural persistence. That is, differences in experience with syntax can change subsequent language performance, and the changes can be observed in both language production and comprehension. However, the effects in comprehension and production appear to differ. In comprehension, persistence is typically found when the verbs are the same in primes and targets; in production, persistence occurs without verb overlap. The contrast suggests a theoretically important hypothesis: parsing in comprehension is lexically driven while formulation in production is structurally driven. A major weakness in this hypothesis about comprehension-production differences is that its empirical motivation rests on the outcomes of experiments in which the priming manipulations differ, the primed sentence structures differ, and the measures of priming differ. To sharpen the comparison, we examined structural persistence with and without verb overlap in both reading comprehension and spoken production, using the same prime presentation procedure, the same syntactic structures, the same sentences, and the same participants. These methods yielded abstract sructural persistence in comprehension as well as production. A measure of the strength of persistence revealed significant effects of priming and verb overlap without significant comprehension—production differences. This argues for uniformity in the structural mechanisms of language processing.

Keywords

structural persistence; syntactic priming; language comprehension and production

1. Introduction

1.1 Using Language

Fundamental to the explanation of how humans communicate is an understanding of the mental processes that support language comprehension and production. A crucial requirement of successful communication is that speakers and listeners can access similar

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information about words and how words combine to express an idea. Thus, English listeners understand English speakers because they make use of shared knowledge about English words and syntactic rules. The same listeners experience speech in unknown languages as meaningless streams of sound. The simple difference is that knowing the speaker's language allows the listener to develop an idea that is similar enough to the speaker's that communication occurs. How this happens remains a mystery. How can an idea become sound, and sound become a vestige of the same idea? In the current study, we tested a hypothesis about what the syntactic systems of language production and comprehension do to make this feat possible.

Given how little we know about the relationship between language comprehension and language production, the simplest workable alternatives are obvious: Speakers and listeners call on similar information in similar ways, or they call on similar information in different ways. The information must be similar or communication would founder, but how the information is used could be the same or different in the two modalities. A strong hypothesis is that speakers and listeners know similar things and use their knowledge in similar ways (Bresnan & Kaplan, 1984; Kempen, Olsthoorn, & Sprenger, 2012; Pickering & Garrod, 2013; Sag & Wasow, 2011). Yet it is undeniable that listeners can understand words and sentences that they do not and perhaps cannot produce (Clark & Malt, 1984), that comprehension and production begin and end with different information, and that the peripheral sensory and motor apparatus for sensation and action are necessarily distinct. Even the creation of computational models in which comprehension and production call on the same information in the same ways is far from straightforward (Fodor, Bever, & Garrett, 1974). This argues for differences between listening and speaking.

Speculation aside, the debate is an empirical one with proponents and compelling evidence on both sides. Support for separable processing systems across comprehension and production comes from several areas of study, including the emergence of comprehension before production in language acquistion (Benedict, 1979; Gertner, Fisher, & Eisengart, 2006; Tomasello, 2000), the neuropsychological impairments that yield double dissociations between modalities in aphasia (Caramazza, 1997; Hillis & Caramazza, 1995; Goodglass & Kaplan, 1972; Linebarger, Schwartz, & Saffran, 1983), and the sheer difficulty of performance, with production seeming much harder (for instance, in driving; Lee & Watter, 2013; Recarte & Nunes, 2003). Nevertheless, there are counterarguments resting on evidence that is more consistent with substantial similarity across production and comprehension. In language acquisition, fine motor control may account for timing differences (Bonvillian, Orlansky, & Novack, 1983; Petitto & Marentette, 1991). In neuropsychological impairments, deficits in general cognitive resources might obscure underlying uniformity (Caplan, 1996; Caplan & Waters, 1995; Caplan, Waters, DeDe, Michaud, & Reddy, 2007). Apparent differences in difficulty could stem from people's typical failure to create as much representational detail after listening as before speaking, even though such detail is achievable (Bock, Dell, Garnsey, Kramer, & Kubose, 2007; Kempen et al., 2012).

Particularly compelling observations about the relationship between comprehension and production come from situations where the two modalities continuously interact, like self-

monitoring and conversation. Self-monitoring of one's own speaking and listening could depend on tight coupling between comprehension and production (Garrett, 1980; Levelt, 1983, 1989; Townsend & Bever, 2001), just as seamless interaction between comprehension and production is a necessity for coherent conversation. In both of these instances, episodes of comprehension may have an immediate impact on upcoming production, and vice versa. Garrod and Pickering (2004) described the mutuality between comprehension and production as a progressive process of *alignment* between conversation partners. As conceived, alignment means that speakers and listeners develop the same linguistic representations for many kinds of referring expressions at many levels (Brennan & Clark, 1996, Watson, Pickering, & Branigan, 2004), including syntactic structure (Branigan, Pickering, & Cleland, 2000).

The linkage between language comprehension and production is a focus of current research on structural priming and persistence. Structural priming (incidental experience with a syntactic structure) and structural persistence (incidental adaptation to the same structure) have consequences for both speakers and listeners. (Note our use of the term *priming* to refer to experience with a structure and *persistence* to refer to structural consequences of that experience.) Whether the consequences or the mechanisms of priming are the same is a matter of debate. In the next two sections we consider the implications for this debate of existing findings about structural persistence.

1.2 Structural Persistence in Language Production

What is structural persistence? Descriptively, structural persistence is the product of a structure-specific influence of an experienced syntactic pattern on later episodes of comprehension and production. It can arise even when lexical, semantic, and thematic information differ between a priming exposure and subsequent encounters with, or uses of, the same structure. For example, speakers who say *The 747 was landing by the control tower* are later on more likely to say *The mailman is being chased by a dog* than they would otherwise be, using a passive structure in the ensuing sentence even when its voice, topic, and just about everything else changes (Bock 1986, 1989; Bock & Loebell, 1990).

Persistence of structure in language production has been observed for several kinds of structures in different languages (Bock, 1986; Bock & Loebell, 1990; Cleland & Pickering, 2003; Corley & Scheepers, 2002; Hartsuiker & Kolk, 1998; Scheepers, 2003; Hartsuiker & Westenberg, 2000; Konopka & Bock, 2009; Pickering & Branigan, 1998), in young children (Huttenlocher, Vasilyeva, & Shimpi, 2004; Savage, Lieven, Theakston, & Tomasello, 2003; Shimpi, Gamez, Huttenlocher, & Vasilyeva, 2007), in spontaneous speech (Gries, 2005), and in bilinguals, across their languages (Hartsuiker, Pickering, & Veltkamp, 2004; Loebell & Bock, 2003; Shin & Christianson, 2009). Most important for present purposes is that persistence in production arises regardless of whether priming occurs in an episode of language production or language comprehension (Branigan, Pickering, & Cleland, 2000; Lombardi & Potter, 1992; Potter & Lombardi, 1998), with the same strength and duration (Bock, Dell, Chang, & Onishi, 2007). That is, persistence in language production is a cross-modality phenomenon.

The occurrence of structural persistence between prime and target structures, without other shared information, is one of its theoretically most provocative features. What seems to persist is an abstract syntactic process or representation. Yet when information overlap *is* present, when specific words recur in specific structures, there is an increase in the magnitude of persistence (Cleland & Pickering, 2003; Pickering & Branigan, 1998). The increase has been demonstrated chiefly (but not exclusively) with the repetition of verbs, which play a prominent part in the syntax of a sentence. This lexically dependent effect, often called the *lexical boost*, implies the interaction of a specific word effect with a general syntactic effect.

1.3 Comparing Structural Persistence in Language Comprehension and Production

The lexical boost suggests that individual words can strongly influence syntactic processes. Curiously, though, the impact of lexical repetition on persistence has been found to differ in the priming of language production by earlier episodes of production compared to the priming of comprehension by earlier episodes of comprehension. In production, abstract and lexically boosted persistence are both well attested; in comprehension, lexically boosted persistence alone is commonly observed.

Research on structural priming in comprehension suggests that, as in production, the effect of understanding a particular structure persists in a way that influences subsequent comprehension of the same structure (Arai, van Gompel, & Scheepers, 2007; Carminati, van Gompel, Scheepers, & Arai, 2008; Thothathiri & Snedeker, 2008a, b; Tooley, Traxler, & Swaab, 2009; Traxler & Tooley, 2008; Traxler, 2008). For example, after reading a sentence with a reduced relative clause (e.g. *The man watched by the woman was tall and handsome*), subsequent reduced-relative sentences are read faster (Traxler & Tooley, 2008) and with less disruption (reflected in smaller P600s in measures of event-related potentials; Ledoux, Traxler, & Swaab, 2007; Tooley et al., 2009).

Similar results have been found in auditory comprehension with different forms of dative sentences (prepositional-object and double-object structures like *The boy gave a flower to the girl* and *The boy gave the girl a flower*, respectively; Arai et al., 2007; Carminati et al., 2008). When listeners performed a task in which scenes corresponding to such sentences were displayed while the sentences were presented, participants showed different patterns of anticipatory eye movements to individual objects depending on which structure was primed. For instance, after double-object priming, listeners who heard “The boy gave” tended to look at the picture of the girl sooner than the picture of the flower. This suggests that the double-object form persisted in a way that biased later parsing of dative sentences toward post-verbal indirect objects (e.g. *the girl*) rather than direct objects (e.g. *the flower* after *The boy gave…*).

The distinctive feature of structural persistence in language comprehension is that the reliability of the effects often hinges on the prime and target sentences having the same verb. So, to see persistence after the reduced-relative prime *The man watched by the woman was tall and handsome*, the target should include the verb *watch* (e.g. *The mouse watched by the cat hid under the table).* Likewise, for datives like the pair above, repetition of the verb *give* is typically needed for persistence to be observable. With different prime and target verbs,

the evidence for persistence in comprehension is scarce (though not completely absent; see Pickering et al., 2013, Thothathiri & Snedeker, 2008a, b; Traxler, 2008; see also Scheepers & Crocker, 2004 for evidence of constituent order priming in comprehension). This casts doubt on the reliability of abstract persistence of structure on its own.

The centrality of lexical support to structural persistence in comprehension points toward a crucial contrast with language production. In production, abstract persistence not only occurs in the absence of lexical support, but can also last for a long time (Bock & Griffin, 2000; Kaschak, 2007; Kaschak, Kutta, & Schatschneider, 2011; Luka & Choi, 2012). Yet the increased effect of structural priming that stems from lexical repetition does not last, instead declining quickly (Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Venderelstet al., 2008; Konopka & Bock, 2005). This means that persistence in production cannot depend on lexical support. For comprehension, lexically boosted persistence has been shown to survive across two intervening sentences (Pickering, McLean, & Branigan, 2013; Tooley, Swaab, Boudewyn, Zirnstein, & Traxler, in press), though its longer-term impact is unknown.

The contrast between production and comprehension in the abstractness of persistence hints at fundamental differences in processing. In language production, speakers can start out with an abstract, rudimentary syntactic structure to which words are bound as the structure unfolds (Bock & Ferreira, in press). In comprehension, because listeners encounter words one at a time, the structural information used for parsing can come from specific-word information in the mental lexicon (e.g., Boland & Boehm-Jernigan, 1998; Garnsey, Pearlmutter, Myers, & Lotocky 1997; Trueswell, Tanenhaus, & Garnsey, 1994). This is consistent with lexicalist models of language comprehension (MacDonald, Pearlmutter, & Seidenberg, 1994). In essence, language production may build on abstract structure while language comprehension builds on words.

This intuitively attractive and theoretically profound claim is consistent with most existing findings about structural persistence in language production and comprehension. Yet despite its appeal, the claim remains tenuous. Its support comes from contrasts between production and comprehension priming in distinct experiments where the initial priming experiences, and just about everything else, differ. There are differences in prime presentation techniques, in tested structures, and in the depth of processing required by the tasks. In comprehension, structural processing is assessed in complex structures and measured as it proceeds, calling on reading times, modulations in the EEG signal, or anticipatory eye movements to visual referents. In production, structural formulation is most often assessed with simple sentence structures and measured from the outcomes of picture description and sentence completion. The upshot is that existing research on structural persistence offers precious little evidence for fundamental differences in the syntactic components of speaking and understanding. What evidence there is comes from experiments that lack an essential element: A manipulation of modality.

A more compelling test of the hypothesis that different structural processes are at work requires a more persuasive equation of the priming that precedes language production and comprehension. In the present experiment, we assessed structural persistence using the same

priming procedure, the same sentences and sentence structures, and the same participants, at the same time.

1.4 Overview of the experiment

In order to create a priming environment that was the same across modalities, we used a modified version of a task introduced by Potter and Lombardi (1990). The task splits prime exposure into three parts. First, participants are shown a word-by-word, rapid serial visual presentation (RSVP) of a prime sentence. Then they complete a short distractor task, which serves to disrupt verbatim memory of the sentence while keeping the message intact. Third and finally, participants try to repeat the priming sentence aloud. This prime trial is followed by an identical three-part trial in which a target sentence is presented in RSVP. The structures of the RSVP prime and target sentences are manipulated to have either matching or mismatching syntactic structures, drawn from structural paraphrases such as the dative alternation. Persistence of structure is indicated when participants are more likely to produce the target sentence using syntax that matches, rather than mismatches, the syntax of the prime sentence. This task successfully elicits structural persistence after priming from comprehension or production (Konopka & Bock, 2009; Lombardi & Potter, 1992; Potter & Lombardi, 1998).

In our adaptation, the comprehension and production priming procedures were equivalent up to the point when target sentences were produced (spoken aloud) or comprehended (read silently). Production and comprehension trials were interleaved pseudorandomly, to ensure comparability in expectations and preparations for speaking or reading. The conditions thus equated the effort and depth of prime processing for both modalities, in addition to equating the priming and target sentences themselves.

The hypothesis that structural processes are more lexically driven and less abstract in comprehension than in production would get support from a difference in the effects of lexical repetition on structural persistence. Specifically, if persistence in comprehension depends on lexical overlap between prime and target sentences, while persistence in production does not, the existence of a real disparity in the mechanisms of structural processing becomes more likely. Furthermore, if the *magnitude* of persistence is demonstrably larger in one modality than the other, the probability of modality differences in the stability or the demands of structural processing increases. If, however, abstract structural persistence emerges in both modalities, at similar magnitudes, there is a stronger case to be made for parity in the structural processes of language comprehension and production.

2.1 Method

2.1.1 Participants

The participants were 286 students and community members from the University of Illinois who were compensated with either course credit or $10. All participants were native speakers of English with normal or corrected-to-normal vision. Of the 286 participants, 30 were excluded from analyses due to (a) learning a different language prior to learning

English (n=1), (b) computer error (n=2), or (c) failing to produce enough scorable responses (n=27). The 256 remaining participants were included in all analyses.

2.1.2 Materials

The experimental stimuli consisted of 128 sentence pairs, divided into the types illustrated in Table 1. Of the pairs, 64 were transitives (consisting of a main clause form and a reduced-relative clause form, adapted from Tooley et al. 2009) and 64 were datives (a prepositional object form and a double-object form). The dative sentences contained either verbs whose prepositional-object forms take the preposition *to* (*The widow gave the Mercedes to the church*) or verbs that take the preposition *for* (*The mother cut some steak for her son*) in order to increase the variety of dative verbs that could be used. The set was divided evenly between *to*-datives and *for*-datives.

All main clause transitives had the structure [[NOUN PHRASE][[VERB PHRASE][[NOUN PHRASE][RELATIVE CLAUSE]]]], (e.g. *The nanny scrubbed the girl who was filthy*) and all reduced-relative clause transitives had the structure [[NOUN PHRASE][[RELATIVE CLAUSE]][VERB PHRASE]]] (e.g. *The girl scrubbed by the nanny was filthy*). The difference between the main clause transitives and the reduced relatives was that in the main clauses, the initial verb was the main verb of the sentence and the following noun phrase was the direct object, whereas in the reduced relatives the initial verb was a past participle. These two structures were indistinguishable from one another up until the word that followed the initial verb.

In the datives, all of the prepositional-object forms had the structure [[NOUN PHRASE] [[VERB PHRASE][VERB][NOUN PHRASE][[PREPOSITIONAL PHRASE[NOUN PHRASE]]]] (e.g. *The junkyard shipped some damaged cars to the dealer*), and all the double-object datives had the structure [[NOUN PHRASE][[VERB PHRASE][VERB] [NOUN PHRASE][NOUN PHRASE]]] (e.g. *The junkyard shipped the dealer some damaged cars*). The two dative structures diverged after the noun phrase that followed the verb, where prepositional-object datives had a preposition and double-object datives had a second noun phrase.

In each pair, both structures had lexical variants in which the verb differed. In a transitive pair the main-clause form had two lexical variants and the reduced-relative form had two variants; likewise, each prepositional and double-object dative pair had two lexical variants. As in Tooley et al. (2009), the lexical variants of both forms in an individual pair were created with the same verb. For example, the transitive pair that used the verb *scrubbed* had lexical variants that used the verb *clean*, and the dative pair that used the verb *shipped* had lexical variants that used the verb *hauled*. These verb variants were chosen to be conceptually similar, enough so that varying the identity of the verb did not greatly alter the interpretation of the sentence. Tooley et al. (2009) showed that conceptual similarity between verbs in primes and targets was by itself insufficient to yield a lexical boost in language comprehension, so the use of similar materials in the present experiment creates a benchmark for comparing demonstrated lexical-boost effects in language comprehension with outcomes in production.

The two verbs that were used in each transitive pair differed from the two verbs used in all other pairs. For datives, because of the restricted number of dative verbs in English, there were two pairs containing the same verb variants. However, the two sentence pairs with the duplicate verb-variants occurred in separate lists so that individual participants received only one instance of every dative verb across the priming sentences.

A set of 130 filler sentences was composed in varying structures (cleft, locative, main clause, full relative clause, intransitive, copula, infinitival complement, etc.). The fillers were designed to increase the structural diversity of the sentences.

To implement the priming manipulation, every sentence was yoked to another sentence of the same type (transitive to transitive, and dative to dative) to create 128 yoked sets. Among the datives, *to*-datives were always linked with other *to*-datives, and *for*-datives were always linked with other *for*-datives. The yoked sets were assigned to one of two master lists, each with 64 sets (32 transitive and 32 dative). Dative sets were assigned such that each of the dative verbs occurred only once in a master list.

From each yoked set of both sentence types, eight prime-target trial sequences were created (see Table 1). There were four primes in each of the two structures of each sentence type, two for each of the lexical variants, and two targets, one in each structure. This created equal numbers of prime-target sequences in which the prime and target had the same or different structures and, within the same/different structure sequences, the same or different lexical variants. Sequences with the same structure constituted *primed* trials; sequences with different structures constituted *unprimed* trials. Sequences with matching verbs were *same-verb* trials; sequences with mismatching verbs were *different-verb* trials. Only one version of the eight combinations of the yoked sentences appeared on each list. Across lists, each of the eight combinations occurred once. Thus, for the transitives, the counterbalancing yielded priming trials in the following four sequences on every list:

1. *main-clause primed*: main-clause prime, main-clause target (MC/MC)
2. *main-clause unprimed*: reduced-relative prime, main-clause target (RR/MC)
3. *reduced-relative-clause primed*: reduced-relative prime, reduced-relative target (RR/RR)
4. *reduced-relative-clause unprimed*: main-clause prime, reduced-relative target (MC/RR).

Likewise, for the datives, every list contained eight priming trials (four same-verb, four different-verb) in four sequences

1. *prepositional-object primed*: prepositional-object prime, prepositional-object target (PO/PO)
2. *prepositional-object unprimed*: double-object prime, prepositional-object target (DO/PO)
3. *double-object primed*: double-object prime, double-object target (DO/DO)
4. *double-object unprimed*: prepositional object prime, double-object target (PO/DO).

Eight lists were generated from each of the two master lists to counterbalance (a) the priming structures (main or reduced-relative for transitives; prepositional or double-object for datives); (b) the structural match between primes and targets; and (c) the lexical match of the prime and target. Every list contained just one prime-target sequence from each of the yoked sentence sets, and equal numbers of prime-target sequences of each of the eight types. The prime-target sequences alternated between datives and transitives throughout every list, with each sequence flanked by fillers.

Finally, to counterbalance the prime and target status of each individual sentence, the prime-target sequences in each of the 16 lists were reversed. This meant that for each yoked pairing, both sentences served alternately as primes and targets. This brought the number of stimulus lists to 32.

Four filler items were placed at the beginning of each stimulus list, and other fillers were randomly selected to appear between each prime-target pair thereafter. Two fillers separated each prime-target pair. All fillers and their positions remained the same across lists.

2.1.3 Procedure

Figures 1 and 2 illustrate the sequence of events on the prime-target trials for production and comprehension, respectively. Each trial began with nine asterisks in the center of the computer screen for 200 ms, to draw attention to the spot where the words of the sentence would be presented. Then a sentence was presented in rapid serial visual presentation (RSVP), one word at a time (100 ms per word), in the center of the screen. All words and symbols were presented in black, 32 pt Courier font, unless otherwise stated.

After the last word of the RSVP sentence, a mask consisting of eleven number symbols (#) was presented for 100 ms. Next, a digit distractor task was inserted to prevent sentence rehearsal: A string of five digits was presented simultaneously for 533 ms, followed by 10 ms of blank screen, then a 500 ms display of a spelled-out number that did or did not correspond to one of the digits, followed by another 10 ms of blank screen. Participants then saw the words *Yes* and *No* side-by-side on the screen until they responded with one of two button-presses signaling that the spelled-out number had or had not occurred (*yes* or *no* response) in the preceding string of digits. Participants received immediate feedback about the accuracy of their response in the form of a 500 ms display of a smiling (correct) or frowning face (incorrect), centered on the screen.

The continuation of each trial was contingent on whether it was a Production trial or a Comprehension trial. On Production trials (Figure 1), participants saw the word *Repeat* in the center of the screen as the cue to repeat the sentence aloud. The word remained on the screen until the participant pressed the spacebar, signalling completion of the repetition. The spoken sentences were recorded for later coding. After the sentence repetition, participants were prompted to decide if they had produced the sentence accurately (verbatim), selecting the corresponding Same or Different button on the keyboard (the *v* or *d* keys, respectively labelled *S* or *D*). Then the next trial began immediately.

On a Comprehension trial (Figure 2), events after the digit-memory task proceeded with a self-paced, moving-window reading task. Participants saw the word *Read* in red, in the center of the screen for 500 ms. Next, the first word in the sentence appeared in black at the left, followed by a series of blanks denoting each upcoming word in the sentence. Participants pressed the spacebar to view each successive word, causing the current word to be replaced by a blank space and the upcoming word to replace the next blank space. This continued until all the words in the sentence had been read, with the final word replacing the last of the blanks, accompanied by a period. Participants were instructed to read the sentence silently to themselves, and reading time for each word was recorded (in terms of the interval between space-bar presses). After each self-paced sentence, participants were prompted to decide whether the sentence they read was exactly the same as, or different from, the rapidly presented sentence they originally saw. The words *Same* and *Different* appeared on the screen until participants responded, exactly as on Production trials, with the next trial following immediately. On experimental trials, the self-paced sentence was always identical to the RSVP sentence.

Every priming episode consisted of consecutive prime and target trials, each with the same sequence of events and the same task. So, a Production priming trial was always followed by a Production target trial, and a Comprehension priming trial was always followed by a Comprehension target trial. The modality of prime presentation, however, was unpredictable. In the 32 stimulus lists, half of the item pairs from each combination of prime-target types were assigned to the comprehension task (32 on each list) and half to the production task. To counterbalance task modality (comprehension or production) for every prime-target sequence, the modality assignments on a given list were reversed, effectively creating another set of 32 presentation lists, for a total of 64. Each of these 64 lists was also presented in two different orders, once forward and once backward.

For each priming trial, this paradigm enabled identical processing of the priming sentence in comprehension and production, up until the point when the participant was asked to read or repeat the just-presented prime. At this point the events in comprehension and production necessarily diverged, to create the manipulation of priming modality. The presentation of the target sentences differed in the same way, for the same reason. (One consequence was that in comprehension-priming sequences there were two successive comprehension exposures to the priming sentence, whereas production-priming sequences contained alternating episodes of reading and speaking. Assuming that comprehension-to-production priming is comparable in magnitude to production-to-production priming, as in Bock et al., 2007, the mixed-modality structural exposures in production should be roughly equivalent to two comprehension-priming episodes.)

The filler-sentence trials were positioned between Production or Comprehension tasks at random, so as to form a pseudo-random sequence of events and further reduce the chance that participants could predict whether they would have to repeat or read an upcoming sentence. Filler trials were the same on all lists and occurred in the same positions, always in the same modality (either as a comprehension trial or a production trial). The filler trials also served to ensure that the Same/Different judgments in the comprehension task were germane: in all lists, half of the fillers that occurred on comprehension trials contained a

change from the initially presented RSVP sentence to the self-paced sentence. The changes included a substitution of a new word for an old one (10 instances), a syntax change (7 instances), an addition of a word to the sentence (6), a removal of a word from the sentence (4), or a completely new sentence (5). Fourteen of these changes altered the propositional meaning of the sentences. The same fillers with the same filler-modality variations occurred on all lists.

An error in list coding altered the balancing of the modality factor in the design. In the lists used for half of the participants (128), the modality of the prime+target trials was assigned randomly. This created small changes in the number of Comprehension and Production trials in each condition. For the remaining participants, the modality assignments were constrained to be fully balanced. The patterns of results for the two sets of data were nonetheless the same, so the results reported below are based on the entire group of 256 participants.

At the beginning of the experiment, participants read the instructions from the computer monitor at the same time as the experimenter presented them aloud. The instructions explained that there would be sentences presented very rapidly in the center of the screen, followed by a set of digits, and then a single digit-name printed as a word. The participants were told to silently read and remember the sentence, and then determine if the printed number was in the set of digits. They then had to either repeat aloud the sentence that was presented or silently read a sentence displayed one word at a time, and finally determine if what they said or read was the same as the sentence they originally saw. No feedback about the same—different judgment was provided.

All of the participants completed two sets of six practice trials, half comprehension and half production. There was a break in between the practice sets, and before the onset of experimental trials, to encourage clarification questions and to check on understanding and correct performance of the task.

Participants were randomly assigned to one of the 64 lists, half receiving the forward order and half receiving the backward order. They were run individually in a private room with the experimenter present. The experiment was controlled by a Macintosh Mini running MatLab software (Psychophysics Toolbox), with materials presented on a 17″ monitor. Participants gave informed consent and completed a language history questionnaire before the experiment began and received debriefing afterwards. The entire session lasted about 1 hour.

2.1.4 Design

Every participant received eight of the 128 items in every cell of the design formed by crossing the factors of Priming (Primed, Unprimed), Verb Overlap (Same, Different), and Sentence Type (Transitive, Dative). Each received exactly four (or an average of four) items in each modality (depending on whether item modality was fixed or assigned randomly). The 64 individual items of each of the two types (Transitive or Dative) were presented to 16 participants in every cell of the design that crossed Priming and Verb Overlap. On average, each item yielded a maximum of eight observations from reading and and eight from production.

2.1.5 Scoring

The scoring procedures were different for the production and comprehension responses. We describe these procedures in turn.

Production—On prime and target production trials, the recordings of the sentences that participants repeated aloud were coded for syntactic structure and the verb produced. On target trials, when the verb and the structure used in the sentence were the same as the RSVP sentence (apart from changes within noun phrases, such as noun substitutions, determiner changes, and omissions of adjectives), the response was coded as *correct*. If the verb was correct but the sentence's form was the structural alternative for the sentence type, the response was coded as a *switch*. On target trials where the syntactic structure of the response was not one of the two structural alternatives (main clause or reduced relative for the transitives, and prepositional object or double object for the datives), or the verb was not repeated exactly, the response was excluded from analysis. For the priming sentences, if the prime was not coded as correct, the subsequent target response was always excluded from analysis regardless of its status.

Participants were replaced when they did not succeed in producing at least two correct target responses. That is, a correct target had to follow a correct prime for at least two prime+target sequences. Substitute participants received the same lists as the participants they replaced.

Accuracy on the same—different judgment was not taken into consideration or used as a criterion for retention of trial data. Across the trials that were retained for analysis, 48% of the prime repetitions and 40% of the target repetitions were judged *same*.

Comprehension—The self-paced reading times for the comprehension target trials were calculated for the sentence regions of interest. The regions were the *verb*, the *critical* region (the words immediately following the verb that made up the noun phrase or *by* + noun phrase), and the *spillover* region (the two words immediately following the critical region). Reading times in each region consisted of the total time spent reading the words in the region. For example, in the main clause sentence *The nanny scrubbed the girl who was filthy*, the verb region included the verb *scrubbed*, the critical region was *the girl*, and the spillover region was *who was*. In the reduced-relative clause version of the sentence (*The girl scrubbed by the nanny was filthy*) the verb region consisted of the verb *scrubbed*, the critical region was *by the nanny*, and the spillover region was *was filthy*. The critical regions reflect the point at which participants could first differentiate between the two structural alternatives, although the sentences were not yet completely disambiguated. Criteria for critical regions were the same as in other studies of structural priming during online comprehension of transitive (e.g., Traxler & Tooley, 2008; Tooley et al., 2009) and dative structures (e.g., Arai et al., 2007; Thothathiri & Snedeker, 2008).

As in production, accuracy of the same—different judgment was not used as a criterion for retention of trial data. Across the trials that were analyzed, 82% of the prime repetitions and 92% of the target repetitions were judged *same*.

2.2 Results

Figure 3 shows the broad patterns of persistence in comprehension and production. The effects in comprehension are given as the difference between primed and unprimed reading times, and in production as the proportions of primed targets produced. The height of the bar for each modality represents total persistence. As the figure shows, structural persistence occurred in both modalities, whether the prime and target verbs were the same or different. The details for calculating and statistically evaluating these effects are presented in the next two sections, first for production and then for comprehension.

2.2.1 Production

Production priming rates in the same- and different-verb conditions are summarized in Table 2 and Figure 4 for the dative and transitive structures separately. The rates are shown in terms of the proportions of responses that occurred in the primed structure, with proportions greater than 0.5 indicating more persistence of the primed than the unprimed structure. The proportions were calculated from the raw number of sentences correctly produced in or switched to the priming sentence's structure, divided by the total number of occasions when either the primed or unprimed structure was produced. On this descriptive measure, priming increased the likelihood of structural persistence for dative and transitive sentences, with proportions exceeding 0.5 for both sentence types. Though the proportions were higher when the verb was the same, persistence was clearly present when the verbs in the prime and target differed.

The likelihood of producing one structural alternative as opposed to the other on each priming trial was statistically estimated in a multiple logistic regression model with random slopes and intercepts. The analysis was carried out on the number of correct and switch target responses on each priming trial, with priming (primed, unprimed) and verb overlap (same, different) as predictor variables (fixed effects), and participants and items as crossed random effects. The predictor variables were centered and weighted to deal with unequal numbers of observations and multicollinearity between predictors. For the model, the prepositional-object datives and main-clause transitives produced on target trials were coded as primary structures while double-object datives and reduced-relative clause transitives were coded as secondary structures. This made it possible to test for effects in the two sentence types with a binary dependent variable.

Table 3 shows the outcomes. The analysis revealed a significant effect of priming but no significant effect of verb overlap by itself or in its interaction with priming. Thus, the structural effect was present regardless of whether the verbs in the prime and target sentences were the same or different.

Additional analyses were conducted to assess priming separately for each of the two sentence types using the same fixed and random effects as the model above. Overall, for both transitives and datives, participants were more likely to produce the primed target structures (see Table 3), though the priming effect for dative sentences was marginal. Verb repetition did not have a significant impact on the structure produced for target sentences of

either type, and the interactions between priming and verb overlap were likewise not significant.

2.2.2 Comprehension

Comprehension priming is shown in Figure 5 as the difference between the primed and unprimed reading times (unprimed – primed) for the critical region in datives and transitives, in the same and different verb conditions. Overall, participants read the critical region of the target sentences faster after prime sentences with the same structure than after prime sentences with a different structure. This priming effect occurred for the transitives regardless of whether the verbs in the prime and target sentences were the same or different. For datives, overall priming was evident only when the verbs were repeated, but this pattern conceals a difference between the two categories of datives that can be seen in Figure 6. In brief, priming was present for *to*-datives regardless of verb repetition but absent to negative in *for*-datives. This disparity is considered in more detail below.

Mean target-sentence reading times for each structure in the three regions of interest are presented in Table 4. To evaluate the patterns statistically for the two types of structures combined, multi-level models with random slopes and intercepts were used to estimate the reading times as a function of the predictor variables of priming (primed, unprimed) and verb overlap (same, different), with participants and items as crossed random effects. The estimates from the model for the critical region are given in Table 5. There was a significant effect of priming, no significant effect of verb overlap, and no significant priming by verb overlap interaction. Effects in the verb and spillover regions fell short of significance (maximum *t*s = −1.39 and −.44, respectively) and are not shown.

In order to look at priming effects for the datives and transitives separately, multilevel models with the same fixed and random effects as the model above were constructed for the critical regions (Table 5). The analysis of the transitives revealed a significant effect of priming, no significant effect of verb overlap, and no significant priming by verb overlap interaction. For datives, none of the effects reached significance, again due to the *for*-dative items.

2.2.4 Comparison of Priming Effects in Production and Comprehension

To compare the magnitudes of persistence in production and comprehension, we computed standardized scores of performance for each item, within each modality. Table 6 shows the means of the scores by condition, and Figure 7 displays the priming effects (the primed-unprimed differences).

The calculation of the standard scores was carried out in the following fashion. First, we used the procedures described earlier for assessing performance in comprehension and production, but on an item-wise basis. Then, an average score was determined for each item, separately in each modality in each of the four conditions (primed/unprimed x same verb/ different verb). This created (a) a distribution of values for comprehension in which effects were represented by the reading times in the critical region for individual items in the unprimed and primed conditions across same verb and different verb conditions; and (b) a

distribution of values for the same items in production, captured in the proportion of target structures produced out of all structures for each item in the unprimed and primed conditions across the same-verb and different-verb conditions. Third, standard scores were computed for each value in each distribution, yielding four *z*-scores (one per condition) for an item in comprehension and the corresponding four *z*-scores for the same item in production.

Interpreted in terms of the respective distributions, priming increased the use of a structure by roughly .40 standard-deviation units in production and .24 in comprehension. The contribution of verb repetition was similar in the two modalities, increasing the priming effects by .19 and .21 in production and comprehension respectively.

Statistical comparisons between production and comprehension were carried out with 95% confidence intervals for pairwise planned contrasts, calculated from an omnibus analysis of variance with items as the random factor (Table 7). The standard scores were the dependent variable, with independent variables defined by the within-item factors of modality, priming, and verb overlap. As calculated from the mean squared error for the three-way interaction, the confidence interval for the difference between the condition means was |.26|. None of the four comparisons between comprehension and production exceeded this value: When the verb was the same in the prime and target, production and comprehension differed by .16 (.19 and .03 in the primed and unprimed conditions, respectively); when the verb changed, the corresponding difference was .18 (−.03 and −.21 in the primed and unprimed conditions; negative values reflect higher standard scores in comprehension than in production).

Analogous contrasts were used to assess the increased priming effect associated with lexical repetition in the two modalities combined. The 95% planned-comparison confidence interval, calculated from the two-way interaction between priming and verb overlap in the omnibus analysis, was |.17|. In the primed condition, the increase in persistence due to a repeated verb was .21, exceeding the confidence interval. In comparison the unprimed difference between same and different verbs was near zero (.01). The magnification of persistence with verb repetition thus exceeded the margin of error, consistent with the presence of a lexical boost.

Apart from these theoretically critical effects, the omnibus analysis of variance (Table 7) disclosed an interaction between modality and verb overlap with no connection to priming. The interaction reflects a greater impact of repeated verbs on eliciting sentences for production than on reading times in comprehension, regardless of priming. So verb repetition increased the response rate in production by .17 standard-deviation units and decreased reading speed in comprehension by .10 standard-deviation units.

One other point deserves comment. Figure 7 shows the numerically larger but statistically negligible ($F < 1$) priming effect for production compared to comprehension. The source of this difference was once again the *for*-dative anomaly in comprehension that was absent from production.

3. Discussion

This experiment constituted a large-scale controlled comparison between sentence comprehension and production in how structural priming plays out. In both modalities, structural priming yielded structural persistence. The persisting structures were abstract, in the sense that persistence emerged regardless of modality and, more important for present purposes, regardless of whether the verbs in the prime and target sentences were the same. Verb repetition modestly increased the amount of persistence in the results from the two modalities combined, but it was not essential for persistence in either reading or speaking, with an exception that we turn to later.

In addition to testifying to the abstractness of persistence, the results also permitted an estimate of the relative magnitudes of persistence in the two modalities. Although the estimation procedure was necessarily rough, the statistical outcome was consistent with similarity in strength in the two modalities. Specifically, the between-modality differences in priming effects averaged .17 standard-deviation units, well within the margin of error of |. 26|. This suggests that abstract structural persistence was not only present in comprehension, but was present to approximately the same degree as in production. The lexical boost, though not consistently significant in the single modality analyses, was evident in planned comparisons for the modalities combined, and did not differ between them. In short, the results point to an unexpected uniformity of structural processing in talking and understanding.

3.1 Modality-General Structural Persistence

The innovation in this research comes from the theoretical implications of the resemblance between comprehension and production in their susceptibility to structural and lexical priming. The implications gain weight from the detailed matching of the conditions under which the effects were measured. With equivalent materials, priming tasks, and participants, structural persistence in comprehension looked surprisingly similar to persistence in production in its abstractness and strength. This is consistent with the hypothesis that structural processes work in modality-general ways, and perhaps in the same ways.

A critical dimension of this similarity was the abstractness of persistence. Abstractness is an acknowledged property of structural persistence in production, but in the present experiment it was present in comprehension, too. Structures persisted in the face of differences in the words and meanings of the prime and target sentences, and although the effect increased when verbs were repeated, it did not go away when the verbs changed. This stands in contrast to most other findings about persistence in comprehension, where the norm is that structural primes have little effect in the absence of lexical repetition (Arai et al., 2007; Carminati et al., 2008; Tooley et al., 2009). The current findings, like those of Pickering et al. (2013), Thothathiri and Snedeker (2008a, b), and Traxler (2008), imply that abstract structural persistence does occur in comprehension, and further, that it emerges under circumstances that yield abstract persistence in production. So, comprehending or producing a structure facilitated the later comprehension or production (respectively) of the same structure, even when none of the same content words carried over from the first sentence to the next.

A modality-general explanation of structural persistence gets a different kind of support from research showing that the brain regions that are active during syntactic processing are largely the same in comprehension and production (Menenti, Gierhan, Segaert, & Hagoort, 2011; Segaert, Menenti, Weber, Petersson, & Hagoort, 2012; Segaert, Kempen, Petersson, & Hagoort, 2013). Segaert and colleagues used fMRI to assess changes in brain activity during parallel comprehension and production tasks that included priming manipulations. Priming in both modalities was associated with changes in the left inferior frontal gyrus, the left middle temporal gyrus, and the bilateral supplementary motor area. Critically, the effects observed for trials where the prime and target structures were the same did not differ across modality. These results provide converging evidence that structural persistence in comprehension and production has similar underpinnings.

Of course, the importance of lexical sources of information for structural processing cannot be discounted. Words and structure play joint parts in the ability to understand the language we produce (e.g., Boland & Boehm-Jernigan, 1998; Garnsey et al., 1997; MacDonald et al., 1994; Trueswell, Tanenhaus, & Kello, 1993) and produce the language we understand (e.g., Bock, 1982; 1986; 1987; Pickering & Branigan, 1998). Even so, our findings accord with views of language use where abstract structural processes make a contribution that is distinct and separable from the contributions of individual words (Bock & Ferreira, in press; Bock, 1990).

We observed one puzzling discrepancy between production and comprehension for a variant of the dative sentence structure. In production, datives were susceptible to priming regardless of whether the prime and target sentences were *to*- or *for*-datives. In comprehension, only *to*-datives showed the predicted pattern of persistence. The difference may be explainable in terms of a specific property that distinguishes *to*- and *for*-dative verbs. The majority of the *to*-dative verbs favored the use of a direct object accompanied by an indirect object (e.g. *give* in *give a kiss to the girl* and *give the girl a kiss)*, whereas the majority of verbs in *for*-datives were biased toward a simple transitive reading with a single direct object (e.g. *sew a dress*). The single-object bias means that when a reader encountered the successive words *The girl microwaved her brother…*., the role of *brother* can be construed in a way that would give anyone pause. These temporary anomalies were common enough in the *for*-datives (see Appendix) to interfere with persistence, yielding a negative average priming effect in comprehension. In production, where this effect was not found, participants benefited from the resolution of the anomaly before a message representation was established.

This spotlights one fundamental difference in the operating characteristics of production and comprehension, a difference that was captured in our experimental procedure and measures. Speakers know what they intend to say *before* they say it. Among other things, this is what allows them to directly recognize their own errors of form and meaning. Listeners cannot know the upcoming details of form and meaning until *after* they hear or read them; they lack unambiguous sources of information about the speaker's plans. As a result, comprehension is necessarily different from production in the word-by-word communication of information. Evidently, the reading penalty that temporary anomaly engenders can overwhelm whatever structural support there might be for an upcoming phrase, camouflaging the typically small

effect of structural priming. Indeed, in the present experiment, average reading time for *for* datives after the critical region was 33 ms slower than for *to* datives. Although too variable for statistical confirmation, these spillover effects are suggestive: In word-by-word reading with word-by-word measures of processing, subtle structural effects may be hard to discern among local lexical-semantic calamities.

3.2 Mechanisms of Structural Persistence

If lexical enhancement of persistence as well as abstract persistence can be found in both comprehension and production, lexical repetition is no more a prerequisite for the priming of structure in comprehension than it is in production. What remains to be explained is how the uniformity arises. We consider two accounts.

3.2.1. Implicit learning—To the extent that the pattern and strength of structural persistence are comparable in comprehension and production, it is tempting to consider the possibility that the sources lie in the same underlying mechanisms. It is particularly tempting given that one of the existing accounts of structural persistence in language production, implicit structural learning, extends naturally to language comprehension.

Implicit learning is a type of learning that occurs automatically, without conscious intent, and without declarative memory support after minimal exposure. There is growing evidence to suggest that learning of this kind creates structural persistence within a structure-building system (Ferreira, Bock, Wilson, & Cohen, 2008). Moreover, learning takes place during language comprehension (Bock, Dell, Chang, & Onishi, 2007; Jaeger & Snider, 2013) as well as language production (Bock & Griffin, 2000).

Chang, Dell, and Bock (2006) implemented a computational model of structural persistence in which implicit learning is a consequence of errors in structural prediction. Without using specific lexical information, the model predicts structural transitions and, when a prediction fails, it tunes its predictive procedures accordingly. Significantly, the modality of the model's learning is language comprehension, although the learning is expressed in language production. Thus, procedures are adapted during comprehension for application in *production*, thereby predisposing the use of the same abstract structure in the future.

The Chang et al. (2006) model successfully accounts for key data on abstract structural persistence in language production. But because its successes are rooted in processes of language comprehension, it is natural to suppose that facilitation of structural processes in reading reflects the same error-tuned prediction mechanisms. Our finding of uniformities in within-modality persistence further hints at mechanisms that are the same, perhaps even shared.

One of the most notable features of the Chang et al. (2006) model is that it calls on the same mechanisms for priming and persistence as for initial acquisition of a structure. This helps it to account for evidence that abstract persistence is long-lived (Bock & Griffin, 2000; Bock et al., 2007; Ferreira et al., 2008; Hartsuiker et al., 2008; Kaschak, Kutta, & Schatschneider, 2011; Konopka & Bock, 2005; Luka & Choi, 2012). In its more powerful forms, learning also generalizes. Generalizability is inherent in the abstractness of structural persistence. The

further kind of generalizability implied by the similarities in persistence across and within the modalities of language use points to learning mechanisms with unusual power for developing the kind of interpersonal communication in which speakers and listeners exchange ideas.

3.2.2. Activation—A different proposal about the mechanism behind structural persistence is that it stems from an activation mechanism similar to what is involved in single-word priming effects. Pickering and Branigan (1998) suggested that verbs are represented in a network as nodes (called *combinatorial nodes*) with satellite links to representations of the structures in which individual verbs appear. According to this proposal, processing a verb in a particular structure leads to activation of the node for the verb as well as the relevant combinatorial node. After processing, a vestige of the original activation remains. Then, when processing a subsequent structure, the residual activation biases the processing towards the previously experienced structure. This elicits structural persistence. The account is elegant in that it explains abstract persistence and the lexical boost with the same activation mechanism, combining residual activation at a combinatorial node with residual activation at a linked verb node.

Unfortunately, the activation account fails to explain durable structural persistence and related effects (Hartsuiker et al., 2008; Jaeger & Snider, 2013; Konopka & Bock, 2005). The transience of the lexical boost suggests that it is a separate phenomenon, perhaps rooted in an explicit memory representation that reacts to content-word repetition (Bock & Griffin, 2000). Seen in this way, the lexical boost might be explained in terms of a short-lived binding between a specific verb's representation and the structural formulation process (Bock & V. Ferreira, in press). So instead of a stable representational linkage between specific verbs and combinatorial nodes, the two components of lexically boosted structural persistence would arise within a transient binding mechanism coupled with a learning mechanism that guides or implements the procedures of structural assembly.

3.3 Commonalities and Differences in Language Production and Comprehension

The details of interleaving and triggering the processes of comprehension and production have to differ. Even so, if there are facets of structure-building that can be modality neutral or modality general, there should be reflections of commonality in other structure-dependent kinds of language performance. One example can be found in research on grammatical agreement, where effects of structural processing sometimes crop up in similar ways in production and comprehension (Bock & Miller, 1991; Dank, Deutsch, & Bock, 2013; Deutsch & Dank, 2009; Nicol, Forster, & Veres, 1997; Pearlmutter, Garnsey, & Bock, 1999; Staub, 2009, 2010; Wagers, Lau, & Phillips, 2009).

The major sources of difference between comprehension and production may be extrinsic to dedicated mechanisms of talking and understanding. In particular, the mental depth and fine grain that ideas have to have at the start of language production will rarely be found at the end of language comprehension. The basic requirements of ordinary production include suiting ideas to the context of speech and formulating them for retrieving words and

building structures. These things demand a kind of richness in detail that comprehenders rarely need to achieve.

This is just as true in the laboratory as it is in everyday listening. Listeners extract as much information as they need to perform the job at hand, and rarely more. In experimental tasks, all that is often required is cursory understanding of language as it arrives, or as much understanding as is needed to answer simple comprehension probes (Christianson, Hollingworth, Halliwell, & Ferreira, 2001; Ferreira, Christianson, & Hollingworth, 2001). On a small scale, the practical difference between comprehension and production is analogous to the gulf that separates the comfortable satisfaction of understanding something from the dismay of trying to teach the same thing to someone else.

In the present experiment, central features of the materials and tasks that participants confronted helped to ensure that the same levels of mental and attentional preparedness would be in place for comprehension and production. These features may also help to explain why we were able to detect abstract structural priming effects in comprehension, where previous studies have not consistently done so (e.g., Arai et. al, 2007). Similar steps have been taken in other experiments where structural persistence occurred in comprehension, despite absence of lexical support (Thothathiri & Snedeker, 2008a, b). Thothathiri and Snedeker used a comprehension task that required active use of the information that was being comprehended-- acting out events based on a sentence's structural interpretation (e.g., after hearing *Give the horse the flower*, participants who understood the sentence gave a toy flower to a toy horse).

What all these studies have in common is that accurate performance depended on detailed message-level comprehension. In light of this, it is not surprising that abstract structural persistence was more apparent than in comprehension tasks where the demands for precise structural interpretation are less stringent. With respect to the aim of finding out what comprehension and production have in common, there is great promise in experimental paradigms where successful performance requires successful communication between speakers and listeners: communication that depends on having the same information at the same time (Brown-Schmidt & Konopka, 2008; Brown-Schmidt & Tanenhaus, 2006).

3.4 Limitations

All experiments have limitations, and the current one is no exception. The most likely sources of concern stem from the experimental paradigm, the materials, and the measures we used. It's important to consider how each of these things restrict the generality of the conclusions that we hope to draw.

The advantage of the experimental paradigm was that it allowed the same prime presentation procedure in production and comprehension. However, the ability to evaluate prime-presentation success necessarily differed in the two modalities. On production trials, the effectiveness of priming in establishing the prerequisites for persistence could be judged on the basis of whether participants successfully reproduced the priming verbs and syntactic structures. This made it possible to exclude trials where the prerequisites were not met. A parallel assessment of validity for comprehension priming was not feasible, because

sentence reading patterns offer no unambiguous criterion for successful prime processing. Likewise, the explicit judgments of sentence identity within the comprehension and production priming trials provided no basis for validating prime presentation, in that the judgments could be based on details that are of unlikely relevance to the persistence of syntactic structure. Accordingly, trial exclusions and participant replacements were made mainly on the basis of production performance. The upshot is that comprehension priming permitted a source of variability that production did not, and corresponding noise in measurement.

The necessary exclusion of trials in both comprehension and production, and the unknown variability in comprehension performance, resulted in a loss of sensitivity that is also likely to have affected the statistical evaluation of the lexical repetition effect in the modality-specific measures. Even so, there was an observable increase in persistence in both comprehension and production. This increase was marginally significant in the overall model when the data from the two modalities were normalized and combined for the between-modality comparison, and achieved conventional significance in the planned contrast. This offers assurance that the the effect was not absent. Although it was less prominent than in some other studies, the literature offers several instances where lexical effects were similarly weak or absent (Pickering et al., 2013; Thothathiri & Snedeker, 2008b; Traxler, 2008). The effect's variability highlights a crucial challenge that remains, which is to identify the factors that modulate the impact of lexical repetition on structural persistence.

Another source of uncertainty in the experimental outcomes, here and elsewhere, is the as-yet-unexplained role of different lexical relationships in creating persistence. It seems clear that the presence of identical verbs creates a lexical boost. But in addition, magnified priming effects have been observed with semantically related words (Cleland & Pickering, 2003), translation-equivalent words from different languages (Schoonbaert, Hartsuiker, & Pickering, 2007), and homophonous words (words with the same forms but different meanings; Santesteban, Pickering, & McLean, 2010). In the present experiment, we compared the priming effects of repeated, identical verbs (e.g. *shipped* and *shipped*) to those of non-identical verbs from similar conceptual fields (e.g. *hauled* and *shipped*). If semantic similarity itself makes a lexical contribution to persistence, it compromises the measurement of the lexical boost in the comparison to identical verbs.

Arguing against this are findings from experiments that used the same kinds of identical vs. semantically related verb pairings. Using eye-movement and electrophysiological measures, Tooley et al. (2009) observed persistence only when the prime and target verbs were identical. Semantic overlap on its own failed to increase persistence. At a minimum, then, the materials in the present experiment allow comparisons of lexical effects that are not necessarily compromised by semantic relatedness.

Regarding the comparison between comprehension and production, the experimental measures themselves limit precision. Persistence in production was assessed with a binary measure of the sentence forms produced, with values that depended on which of two structural alternatives was produced. The measure of persistence in comprehension was

reading time, a continuous variable with the potential to tap structual persistence throughout the course of comprehension. This difference in measures motivated the use of standard scores for the comparison of comprehension and production. Of course, it would be considerably better if the same measures were available to tap processes as they occur, at a fine grain, at comparable points in time. Encouragingly, under circumstances in which the same measure could be called upon in order to assess the consequences of comprehension and production priming the outcomes for the two modalities were equivalent. In Segaert et al. (2012; 2013), the measure of persistence was the same and had the same physical source: the brain.

Without dismissing matters like these, one must keep another perspective in mind. Whatever unusual demands our task made, they did not disrupt the building of sentence structure. Whatever unusual properties the experimental materials had, they did not create differences in persistence between production and comprehension. This reinforces the view that the sources of structural persistence lie in a robust ability to extract and generalize structural information, with analogous consequences for talking and understanding.

3.6 Summary and conclusions

The focus in the present research was on syntactic processes and their reflections in reading and speaking. Using a structural priming technique, we examined how the comprehension and production of sentences (the targets of priming) changed in response to experience with previously-experienced sentences (the structural primes). To examine the effect of verb repetition on persistence, the verbs in the priming sentences matched or mismatched the verbs in the target sentences. To align the comparison between comprehension and production, in both modalities the prime and target sentences were identical, the readers and speakers were identical, and the prime presentation procedures were identical. To ensure the same levels of task preparation, the reading and speaking target trials alternated unpredictably in a homogeneous series of experimental events, minimizing task-specific expectations.

The persistence of primed structures was observed in both comprehension and production, regardless of verb overlap between prime and target sentences. When measured similarly, in terms of standard scores, the magnitude of persistence was comparable in the two modalities. These findings suggest that abstract structural persistence occurs in both reading and speaking and to about the same degree. This is consistent with a language processing system in which comprehension and production operate in similar ways and on similar principles.

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Appendix: Experimental Items

Transitives: The first four sentences of each group are primes (RR= reduced-relative clause, MC=main clause; *same* means the prime's verb was the same as the target's and *diff* means the prime and target verbs differed); the last two sentences are the targets.

1 The speaker selected by the group gave a great talk. (RR-same)

The speaker picked by the group gave a great talk. (RR-diff)

The group selected the speaker who gave a great talk. (MC-same)

The group picked the speaker who gave a great talk. (MC-diff)

The architect selected by the firm had years of experience. (RR-Target)

The firm selected the architect who had years of experience. (MC-Target)

2 The junkie watched by the cop walked with a limp. (RR-same)

The junkie observed by the cop walked with a limp. (RR-diff)

The cop watched the junkie who walked with a limp. (MC-same)

The cop observed the junkie who walked with a limp. (MC-diff)

The mouse watched by the cat ate some cheese. (RR-Target)

The cat watched the mouse that ate some cheese. (MC-Target)

3 The student graded by the professor received top marks. (RR-same)

The student evaluated by the professor received top marks. (RR-diff)

The professor graded the student who received top marks. (MC-same)

The professor evaluated the student who received top marks. (MC-diff)

The chef graded by the panel used lots of butter. (RR-Target)

The panel graded the chef who used lots of butter. (MC-Target)

4 The mailman expected by the secretary showed up late. (RR-same)

The mailman anticipated by the secretary showed up late. (RR-diff)

The secretary expected the mailman who showed up late. (MC-same)

The secretary anticipated the mailman who showed up late. (MC-diff)

The caterer expected by the woman brought the serving trays. (RR-Target)

The woman expected the caterer who brought the serving trays. (MC-Target)

5 The prisoners transported by the guards were handcuffed together. (RR-same)

The prisoners moved by the guards were handcuffed together. (RR-diff)

The guards transported the prisoners who were handcuffed together. (MC-same)

The guards moved the prisoners who were handcuffed together. (MC-diff)

The hostages transported by the robbers were terrified. (RR-Target)

The robbers transported the hostages who were terrified. (MC-Target)

6 The teacher loved by the class smiled a lot. (RR-same)

The teacher adored by the class smiled a lot. (RR-diff)

The class loved the teacher who smiled a lot. (MC-same)

The class adored the teacher who smiled a lot. (MC-diff)

The singer loved by the fan married a movie star. (RR-Target)

The fan loved the singer who married a movie star. (MC-Target)

7 The suspect identified by the victim was held for questioning. (RR-same)

The suspect recognized by the victim was held for questioning. (RR-diff)

The victim identified the suspect who was held for questioning. (MC-same)

The victim recognized the suspect who was held for questioning. (MC-diff)

The victim identified by the doctor was in bad shape. (RR-Target)

The doctor identified the victim who was in bad shape. (MC-Target)

8 The troops attacked by the terrorists lost many men. (RR-same)

The troops assaulted by the terrorists lost many men. (RR-diff)

The terrorists attacked the troops who lost many men. (MC-same)

The terrorists assaulted the troops who lost many men. (MC-diff)

A woman attacked by the gang gave up her purse. (RR-Target)

The gang attacked a woman who gave up her purse. (MC-Target)

9 The pitcher wanted by the team had a low ERA. (RR-same)

The pitcher needed by the team had a low ERA. (RR-diff)

The team wanted the pitcher who had a low ERA. (MC-same)

The team needed the pitcher who had a low ERA. (MC-diff)

The actress wanted by the director had red hair. (RR-Target)

The director wanted the actress who had red hair. (MC-Target)

10 The teacher appreciated by the principal organized a fundraiser. (RR-same)

The teacher valued by the principal organized a fundraiser. (RR-diff)

The principal appreciated the teacher who organized a fundraiser. (MC-same)

The principal valued the teacher who organized a fundraiser. (MC-diff)

The secretary appreciated by the accountant kept things organized. (RR-Target)

The accountant appreciated the secretary who kept things organized. (MC-Target)

11 The protesters angered by the politician chanted loudly. (RR-same)

The protesters enraged by the politician chanted loudly. (RR-diff)

The politician angered the protesters who chanted loudly. (MC-same)

The politician enraged the protesters who chanted loudly. (MC-diff)

The governor angered by the liberals campaigned harder. (RR-Target)

The liberals angered the governor who campaigned harder. (MC-Target)

12 The settlers surrounded by rebels began praying. (RR-same)

The settlers encircled by rebels began praying. (RR-diff)

Rebels surrounded the settlers who began praying. (MC-same)

Rebels encircled the settlers who began praying. (MC-diff)

The lions surrounded by the hunters roared. (RR-Target)

The hunters surrounded the lions that roared. (MC-Target)

13 A driver stopped by the policeman had been drinking. (RR-same)

A driver halted by the policeman had been drinking. (RR-diff)

The policeman stopped a driver who had been drinking. (MC-same)

The policeman halted a driver who had been drinking. (MC-diff)

The child stopped by the lifeguard was running. (RR-Target)

The lifeguard stopped the child who was running. (MC-Target)

14 The voters convinced by the mayor reelected him. (RR-same)

The voters persuaded by the mayor reelected him. (RR-diff)

The mayor convinced the voters who reelected him. (MC-same)

The mayor persuaded the voters who reelected him. (MC-diff)

The consumer convinced by the salesman bought the stove. (RR-Target)

The salesman convinced the consumer who bought the stove. (MC-Target)

15 The dog located by the hunter had an injured paw. (RR-same)

The dog discovered by the hunter had an injured paw. (RR-diff)

The hunter located the dog that had an injured paw. (MC-same)

The hunter discovered the dog that had an injured paw. (MC-diff)

The bird located by the scientist was endangered. (RR-Target)

The scientist located the bird that was endangered. (MC-Target)

16 The child scolded by the babysitter went to bed. (RR-same)

The child punished by the babysitter went to bed. (RR-diff)

The babysitter scolded the child who went to bed. (MC-same)

The babysitter punished the child who went to bed. (MC-diff)

The man scolded by the security guard was intoxicated. (RR-Target)

The security guard scolded the man who was intoxicated. (MC-Target)

17 The passengers injured by the drunk driver needed surgery. (RR-same)

The passengers wounded by the drunk driver needed surgery. (RR-diff)

The drunk driver injured the passengers who needed surgery. (MC-same)

The drunk driver wounded the passengers who needed surgery. (MC-diff)

The child injured by the Labrador cried. (RR-Target)

The Labrador injured the child who cried. (MC-Target)

18 The homeowner frightened by the burglar called the police. (RR-same)

The homeowner scared by the burglar called the police. (RR-diff)

The burglar frightened the homeowner who called the police. (MC-same)

The burglar scared the homeowner who called the police. (MC-diff)

A horse frightened by the coyote galloped away. (RR-Target)

The coyote frightened a horse that galloped away. (MC-Target)

19 A spy caught by the FBI agent went to prison. (RR-same)

A spy captured by the FBI agent went to prison. (RR-diff)

The FBI agent caught a spy who went to prison. (MC-same)

The FBI agent captured a spy who went to prison. (MC-diff)

The imposter caught by the detective started to panic. (RR-Target)

The detective caught the imposter who started to panic. (MC-Target)

20 The countess offended by the duke told her husband. (RR-same)

The countess disgusted by the duke told her husband. (RR-diff)

The duke offended the countess who told her husband. (MC-same)

The duke disgusted the countess who told her husband. (MC-diff)

The tutor offended by the delinquent refused to teach him. (RR-Target)

The delinquent offended the tutor who refused to teach him. (MC-Target)

21 The campers hunted by the cougar were in danger. (RR-same)

The camper stalked by the cougar was in danger. (RR-diff)

The cougar hunted the campers who were in danger. (MC-same)

The cougar stalked the campers who were in danger. (MC-diff)

The chipmunk hunted by the owl scurried away. (RR-Target)

The owl hunted the chipmunk that scurried away. (MC-Target)

22 The student helped by a counselor chose a major. (RR-same)

The student assisted by a counselor chose a major. (RR-diff)

The counselor helped the student who chose a major. (MC-same)

A counselor assisted the student who chose a major. (MC-diff)

The surgeons helped by the nurses operated all night. (RR-Target)

The nurses helped the surgeons who operated all night. (MC-Target)

23 The miners rescued by the paramedics recovered slowly. (RR-same)

The miners aided by the paramedics recovered slowly. (RR-diff)

The paramedics rescued the miners who recovered slowly. (MC-same)

The paramedics aided the miners who recovered slowly. (MC-diff)

The man rescued by the sailor was soaking wet. (RR-Target)

The sailor rescued the man who was soaking wet. (MC-Target)

24 The president advised by the general addressed the nation. (RR-same)

The president counseled by the general addressed the nation. (RR-diff)

The general advised the president who addressed the nation. (MC-same)

The general counseled the president who addressed the nation. (MC-diff)

The girl advised by her parents went to college. (RR-Target)

The parents advised the girl who went to college. (MC-Target)

25 The carpenter questioned by the inspector acted nervous. (RR-same)

The carpenter quizzed by the inspector acted nervous. (RR-diff)

The inspector questioned the carpenter who acted nervous. (MC-same)

The inspector quizzed the carpenter who acted nervous. (MC-diff)

The butler questioned by the widow told lies. (RR-Target)

The widow questioned the butler who told lies. (MC-Target)

26 The girl fascinated by the monkey giggled. (RR-same)

The girl captivated by the monkey giggled. (RR-diff)

The monkey fascinated the girl who giggled. (MC-same)

The monkey captivated the girl who giggled. (MC-diff)

The toddler fascinated by the parrot fed him peanuts. (RR-Target)

The parrot fascinated the toddler who fed him peanuts. (MC-Target)

27 The customers ignored by the salesman were impatient. (RR-same)

The customers overlooked by the salesman were impatient. (RR-diff)

The salesman ignored the customers who were impatient. (MC-same)

The salesman overlooked the customers who were impatient. (MC-diff)

A hobo ignored by the conductor snuck aboard. (RR-Target)

The conductor ignored a hobo who snuck aboard. (MC-Target)

28 The woman despised by the doorman wore fur coats. (RR-same)

The woman loathed by the doorman wore fur coats. (RR-diff)

The doorman despised the woman who wore fur coats. (MC-same)

The doorman loathed the woman who wore fur coats. (MC-diff)

The doctor despised by his patients had cold hands. (RR-Target)

The patients despised the doctor who had cold hands. (MC-Target)

29 The clown mauled by a bear sued the circus. (RR-same)

The clown mangled by a bear sued the circus. (RR-diff)

The bear mauled a clown who sued the circus. (MC-same)

A bear mangled the clown who sued the circus. (MC-diff)

The photographer mauled by the pit bull needed stitches. (RR-Target)

The pit bull mauled the photographer who needed stitches. (MC-Target)

30 The juror accused by the judge was held in contempt. (RR-same)

The juror blamed by the judge was held in contempt. (RR-diff)

The judge accused the juror who was held in contempt. (MC-same)

The judge blamed the juror who was held in contempt. (MC-diff)

The employee accused by the supervisor got fired. (RR-Target)

The supervisor accused the employee who got fired. (MC-Target)

31 The child thrilled by the zoo begged to go back. (RR-same)

The child excited by the zoo begged to go back. (RR-diff)

The zoo thrilled the child who begged to go back. (MC-same)

The zoo excited the child who begged to go back. (MC-diff)

The girl thrilled by the actor fainted dead away. (RR-Target)

The actor thrilled the girl who fainted dead away. (MC-Target)

32 The king pleased by the jester pardoned Robin Hood. (RR-same)

The king delighted by the jester pardoned Robin Hood. (RR-diff)

The jester pleased the king who pardoned Robin Hood. (MC-same)

The jester delighted the king who pardoned Robin Hood. (MC-diff)

The baby pleased by a puppy stopped crying. (RR-Target)

A puppy pleased the baby who stopped crying. (MC-Target)

33 The woman astounded by the magician applauded. (RR-same)

The woman amazed by the magician applauded. (RR-diff)

The magician astounded the woman who applauded. (MC-same)

The magician amazed the woman who applauded. (MC-diff)

A man astounded by the astronaut read his biography. (RR-Target)

The astronaut astounded a man who read his biography. (MC-Target)

34 The monkey lifted by the trainer begged for a treat. (RR-same)

The monkey hoisted by the trainer begged for a treat. (RR-diff)

The trainer lifted the monkey who begged for a treat. (MC-same)

The trainer hoisted the monkey who begged for a treat. (MC-diff)

The man lifted by an elephant held on tightly. (RR-Target)

An elephant lifted the man who held on tightly. (MC-Target)

35 The player shoved by the referee missed the goal. (RR-same)

The player pushed by the referee missed the goal. (RR-diff)

The referee shoved the player who missed the goal. (MC-same)

The referee pushed the player who missed the goal. (MC-diff)

The woman shoved by the thief screamed for help. (RR-Target)

The thief shoved the woman who screamed for help. (MC-Target)

36 A child grabbed by the guard had wandered into traffic. (RR-same)

A child seized by the guard had wandered into traffic. (RR-diff)

The guard grabbed a child who had wandered into traffic. (MC-same)

The guard seized a child who had wandered into traffic. (MC-diff)

The mouse grabbed by an eagle squeaked. (RR-Target)

An eagle grabbed the mouse that squeaked. (MC-Target)

37 The girl pulled by her father was wailing. (RR-same)

The girl yanked by her father was wailing. (RR-diff)

The father pulled the girl who was wailing. (MC-same)

The father yanked the girl who was wailing. (MC-diff)

The boy pulled by some playmates struggled. (RR-Target)

Some playmates pulled the boy who struggled. (MC-Target)

38 The Girl Scout startled by the woman dropped her cookies. (RR-same)

The Girl Scout alarmed by the woman dropped her cookies. (RR-diff)

The woman startled the Girl Scout who dropped her cookies. (MC-same)

The woman alarmed the Girl Scout who dropped her cookies. (MC-diff)

The dog startled by the intruder barked. (RR-Target)

The intruder startled the dog that barked. (MC-Target)

39 The man rejected by the woman bought himself a drink. (RR-same)

The man shunned by the woman bought himself a drink. (RR-diff)

The woman rejected the man who bought himself a drink. (MC-same)

The woman shunned the man who bought himself a drink. (MC-diff)

The nerd rejected by the fraternity had no friends. (RR-Target)

The fraternity rejected the nerd who had no friends. (MC-Target)

40 The pitcher replaced by the coach got the win. (RR-same)

The pitcher substituted by the coach got the win. (RR-diff)

The coach replaced the pitcher who got the win. (MC-same)

The coach substituted the pitcher who got the win. (MC-diff)

The actor replaced by the director filed a lawsuit. (RR-Target)

The director replaced the actor who filed a lawsuit. (MC-Target)

41 The aide cheated by the employer lost his pay. (RR-same)

The aide conned by the employer lost his pay. (RR-diff)

The employer cheated the aide who lost his pay. (MC-same)

The employer conned the aide who lost his pay. (MC-diff)

The victim cheated by the insurance agency had medical bills. (RR-Target)

The insurance agency cheated the victim who had medical bills. (MC-Target)

42 The player praised by the scout received a scholarship. (RR-same)

The player complimented by the scout received a scholarship. (RR-diff)

The scout praised the player who received a scholarship. (MC-same)

The scout complimented the player who received a scholarship. (MC-diff)

The pupil praised by the tutor studied extra hard. (RR-Target)

The tutor praised the pupil who studied extra hard. (MC-Target)

43 The child teased by the bully hid at recess. (RR-same)

The child tormented by the bully hid at recess. (RR-diff)

The bully teased the child who hid at recess. (MC-same)

The bully tormented the child who hid at recess. (MC-diff)

The girl teased by the boy slapped his face. (RR-Target)

The boy teased the girl who slapped his face. (MC-Target)

44 The journalist honored by Oprah got his own column. (RR-same)

The journalist revered by Oprah got his own column. (RR-diff)

Oprah honored the journalist who got his own column. (MC-same)

Oprah revered the journalist who got his own column. (MC-diff)

The actress honored by the Academy got an Oscar. (RR-Target)

The Academy honored the actress who got an Oscar. (MC-Target)

45 The swimmer tired by the coach hated the backstroke. (RR-same)

The swimmer fatigued by the coach hated the backstroke. (RR-diff)

The coach tired the swimmer who hated the backstroke. (MC-same)

The coach fatigued the swimmer who hated the backstroke. (MC-diff)

The woman tired by the children wanted a break. (RR-Target)

The children tired the woman who wanted a break. (MC-Target)

46 The CEO cured by the physician returned to work. (RR-same)

The CEO healed by the physician returned to work. (RR-diff)

The physician cured the CEO who returned to work. (MC-same)

The physician healed the CEO who returned to work. (MC-diff)

The baby cured by the nurse had swine flu. (RR-Target)

The nurse cured the baby who had swine flu. (MC-Target)

47 A fireman drenched by the engine crew climbed the ladder. (RR-same)

A fireman soaked by the engine crew climbed the ladder. (RR-diff)

The engine crew drenched a fireman who climbed the ladder. (MC-same)

The engine crew soaked a fireman who climbed the ladder. (MC-diff)

The banker drenched by a window washer changed clothes. (RR-Target)

A window washer drenched the banker who changed clothes. (MC-Target)

48 The contestant fooled by the deejay received no prize. (RR-same)

The contestant tricked by the deejay received no prize. (RR-diff)

The deejay fooled the contestant who received no prize. (MC-same)

The deejay tricked the contestant who received no prize. (MC-diff)

The policeman fooled by the suspect released him. (RR-Target)

The suspect fooled the policeman who released him. (MC-Target)

49 The attorney preferred by the judge was always prepared. (RR-same)

The attorney favored by the judge was always prepared. (RR-diff)

The judge preferred the attorney who was always prepared. (MC-same)

The judge favored the attorney who was always prepared. (MC-diff)

The waitress preferred by the customer got a large tip. (RR-Target)

The customer preferred the waitress who got a large tip. (MC-Target)

50 The players coached by Ron Zook had a bad season. (RR-same)

The players trained by Ron Zook had a bad season. (RR-diff)

Ron Zook coached the players who had a bad season. (MC-same)

Ron Zook trained the players who had a bad season. (MC-diff)

The amateur coached by the pro made the team. (RR-Target)

The pro coached the amateur who made the team. (MC-Target)

51 The cadet instructed by the veteran made a solo landing. (RR-same)

The cadet guided by the veteran made a solo landing. (RR-diff)

The veteran instructed the cadet who made a solo landing. (MC-same)

The veteran guided the cadet who made a solo landing. (MC-diff)

The homeschooler instructed by the neighbors was good at math. (RR-Target)

The neighbors instructed the homeschooler who was good at math. (MC-Target)

52 A first-grader skipped by the bus driver walked to school. (RR-same)

A first-grader missed by the bus driver walked to school. (RR-diff)

The bus driver skipped a first-grader who walked to school. (MC-same)

The bus driver missed a first-grader who walked to school. (MC-diff)

The passenger skipped by the stewardess got no peanuts. (RR-Target)

The stewardess skipped the passenger who got no peanuts. (MC-Target)

53 The baker hired by the market made great bread. (RR-same)

The baker employed by the market made great bread. (RR-diff)

The market hired the baker who made great bread. (MC-same)

The market employed the baker who made great bread. (MC-diff)

One manager hired by the owner worked nights. (RR-Target)

The owner hired one manager who worked nights. (MC-Target)

54 The girl scrubbed by her nanny was filthy. (RR-same)

The girl cleaned by her nanny was filthy. (RR-diff)

The nanny scrubbed the girl who was filthy. (MC-same)

The nanny cleaned the girl who was filthy. (MC-diff)

The doctor scrubbed by the nurse was prepping for surgery. (RR-Target)

The nurse scrubbed the doctor who was prepping for surgery. (MC-Target)

55 The children spoiled by the uncle ate lots of sweets. (RR-same)

The children pampered by the uncle ate lots of sweets. (RR-diff)

The uncle spoiled the children who ate lots of sweets. (MC-same)

The uncle pampered the children who ate lots of sweets. (MC-diff)

The student spoiled by the teacher got the best grades. (RR-Target)

The teacher spoiled the student who got the best grades. (MC-Target)

56 The busboy punished by the manage1r got fewer shifts. (RR-same)

The busboy disciplined by the manager got fewer shifts. (RR-diff)

The manager punished the busboy who got fewer shifts. (MC-same)

The manager disciplined the busboy who got fewer shifts. (MC-diff)

The apprentice punished by the artist swept the studio. (RR-Target)

The artist punished the apprentice who swept the studio. (MC-Target)

57 The parents worried by their kids called a psychologist. (RR-same)

The parents concerned by their kids called a psychologist. (RR-diff)

The kids worried their parents who called a psychologist. (MC-same)

The kids concerned their parents who called a psychologist. (MC-diff)

The captain worried by the pirates could not sleep. (RR-Target)

The pirates worried the captain who could not sleep. (MC-Target)

58 The applicant assessed by the supervisor was not hired. (RR-same)

The applicant evaluated by the supervisor was not hired. (RR-diff)

The supervisor assessed the applicant who was not hired. (MC-same)

The supervisor evaluated the applicant who was not hired. (MC-diff)

The patient assessed by a specialist needed physical therapy. (RR-Target)

A specialist assessed the patient who needed physical therapy. (MC-Target)

59 The superhero crushed by the train was not injured. (RR-same)

The superhero squashed by the train was not injured. (RR-diff)

The train crushed the superhero who was not injured. (MC-same)

The train squashed the superhero who was not injured. (MC-diff)

The jockey crushed by the horses broke both arms. (RR-Target)

The horses crushed the jockey who broke both arms. (MC-Target)

60 The girl hugged by her grandfather missed her mom. (RR-same)

The girl embraced by her grandfather missed her mom. (RR-diff)

The grandfather hugged the girl who missed her mom. (MC-same)

The grandfather embraced the girl who missed her mom. (MC-diff)

The player hugged by the parents played well. (RR-Target)

The parents hugged the player who played well. (MC-Target)

61 The man hassled by the clerk left the store. (RR-same)

The man bothered by the clerk left the store. (RR-diff)

The clerk hassled the man who left the store. (MC-same)

The clerk bothered the man who left the store. (MC-diff)

The woman hassled by the bum had no cash. (RR-Target)

The bum hassled the woman who had no cash. (MC-Target)

62 A runner enlisted by the coach won the race. (RR-same)

A runner enrolled by the coach won the race. (RR-diff)

The coach enlisted a runner who won the race. (MC-same)

The coach enrolled a runner who won the race. (MC-diff)

The soldier enlisted by the recruiter liked the army. (RR-Target)

The recruiter enlisted the soldier who liked the army. (MC-Target)

63 The lady soothed by the singer forgot her troubles. (RR-same)

The lady calmed by the singer forgot her troubles. (RR-diff)

The singer soothed the lady who forgot her troubles. (MC-same)

The singer calmed the lady who forgot her troubles. (MC-diff)

The baby soothed by the nanny fell asleep. (RR-Target)

The nanny soothed the baby who fell asleep. (MC-Target)

64 The cook criticized by the customers made salty food. (RR-same)

The cook critiqued by the customers made salty food. (RR-diff)

The customers criticized the cook who made salty food. (MC-same)

The customers critiqued the cook who made salty food. (MC-diff)

An ice skater criticized by the judge had bad technique. (RR-Target)

The judge criticized an ice skater who had bad technique. (MC-Target)

To-datives (65–96) and *for*-datives (97–128): The first four sentences in each group are primes (PO= prepositional object, DO=double object; *same* means prime verb was the same as the target verb and *diff* means prime verb differed from target verb; the last two sentences are targets

65 The widow gave the Mercedes to the church. (PO-same)

The widow offered the Mercedes to the church. (PO-diff)

The widow gave the church a Mercedes. (DO-same)

The widow offered the church the Mercedes. (DO-diff)

The ballet dancer gave a rose to the girl. (PO Target)

The ballet dancer gave the girl a rose. (DO Target)

66 The arms dealer offered some weapons to the rebels. (PO-same)

The arms dealer gave some weapons to the rebels. (PO-diff)

The arms dealer offered the rebels some weapons. (DO-same)

The arms dealer gave the rebels some weapons. (DO-diff)

The hostess offered the drinks to her guests. (PO Target)

The hostess offered her guests the drinks. (DO Target)

67 Beckham kicked a ball to the fans. (PO-same)

Beckham rolled a ball to the fans. (PO-diff)

Beckham kicked the fans a ball. (DO-same)

Beckham rolled the fans a ball. (DO-diff)

The spy kicked a gun to his partner. (PO Target)

The spy kicked his partner a gun. (DO Target)

68 The rock climber rolled the chalk to his buddy. (PO-same)

The rock climber kicked the chalk to his buddy. (PO-diff)

The rock climber rolled his buddy the chalk. (DO-same)

The rock climber kicked his buddy the chalk. (DO-diff)

The repairman rolled a tire to his assistant. (PO Target)

The repairman rolled his assistant a tire. (DO Target)

69 The rancher brought the horses to the cowboy. (PO-same)

The rancher took the horses to the cowboy. (PO-diff)

The rancher brought the cowboy the horses. (DO-same)

The rancher took the cowboy the horses. (DO-diff)

The bank brought a million dollars to the casino. (PO Target)

The bank brought the casino a million dollars. (DO Target)

70 The prospector took a bag of gold to the gambler. (PO-same)

The prospector brought a bag of gold to the gambler. (PO-diff)

The prospector took the gambler a bag of gold. (DO-same)

The prospector brought the gambler a bag of gold. (DO-diff)

The child took a birthday present to her sister. (PO Target)

The child took her sister a birthday present. (DO Target)

71 The teacher awarded a gold star to the student. (PO-same)

The teacher presented a gold star to the student. (PO-diff)

The teacher awarded the student a gold star. (DO-same)

The teacher presented the student a gold star. (DO-diff)

The panel awarded a scholarship to the class president. (PO Target)

The panel awarded the class president a scholarship. (DO Target)

72 The mayor presented a medal to the hero. (PO-same)

The mayor awarded a medal to the hero. (PO-diff)

The mayor presented the hero a medal. (DO-same)

The mayor awarded the hero a medal. (DO-diff)

The host presented a certificate to the contestant. (PO Target)

The host presented the contestant a certificate. (DO Target)

73 The patient emailed a letter to the insurance company. (PO-same)

The patient sent a letter to the insurance company. (PO-diff)

The patient emailed the insurance company a letter. (DO-same)

The patient sent the insurance company a letter. (DO-diff)

The class emailed a letter to the vice president. (PO Target)

The class emailed the vice president a letter. (DO Target)

74 The writer sent a story to the publisher. (PO-same)

The writer emailed a story to the publisher. (PO-diff)

The writer sent the publisher a story. (DO-same)

The writer emailed the publisher a story. (DO-diff)

The artist sent the sculpture to the museum. (PO Target)

The artist sent the museum the sculpture. (DO Target)

75 The woman mailed the photo to the company. (PO-same)

The woman faxed the photo to the company. (PO-diff)

The woman mailed the company the photo. (DO-same)

The woman faxed the company the photo. (DO-diff)

The violinist mailed some sheet music to the school. (PO Target)

The violinist mailed the school some sheet music. (DO Target)

76 The salesman faxed an order to the warehouse. (PO-same)

The salesman mailed an order to the warehouse. (PO-diff)

The salesman faxed the warehouse an order. (DO-same)

The salesman mailed the warehouse an order. (DO-diff)

The secretary faxed the receipt to the banker. (PO Target)

The secretary faxed the banker the receipt. (DO Target)

77 IBM promised a faster computer to the Sears store. (PO-same)

IBM guaranteed a faster computer to the Sears store. (PO-diff)

IBM promised the Sears store a faster computer. (DO-same)

IBM guaranteed the Sears store a faster computer. (DO-diff)

The student promised cupcakes to the teacher. (PO Target)

The student promised the teacher cupcakes. (DO Target)

78 Tiger Woods guaranteed a donation to the club. (PO-same)

Tiger Woods promised a donation to the club. (PO-diff)

Tiger Woods guaranteed the club a donation. (DO-same)

Tiger Woods promised the club a donation. (DO-diff)

The candidate guaranteed lower taxes to the voters. (PO Target)

The candidate guaranteed the voters lower taxes. (DO Target)

79 The Little Leaguers handed some baseballs to the fans. (PO-same)

The Little Leaguers passed some baseballs to the fans. (PO-diff)

The Little Leaguers handed the fans some baseballs. (DO-same)

The Little Leaguers passed the fans some baseballs. (DO-diff)

The assistant handed the wrench to the plumber. (PO Target)

The assistant handed the plumber the wrench. (DO Target)

80 The collector passed the rare stamp to the appraiser. (PO-same)

The collector handed the rare stamp to the appraiser. (PO-diff)

The collector passed the appraiser the rare stamp. (DO-same)

The collector handed the appraiser the rare stamp. (DO-diff)

The little girl passed a slice of cake to her brother. (PO Target)

The little girl passed her brother a slice of cake. (DO Target)

81 The company rented a house to the homeless family. (PO-same)

The company leased a house to the homeless family. (PO-diff)

The company rented the homeless family a house. (DO-same)

The company leased the homeless family a house. (DO-diff)

The businessman rented a parking spot to the new employee. (PO Target)

The businessman rented the new employee a parking spot. (DO Target)

82 The cycling club leased some bicycles to the hotel. (PO-same)

The cycling club rented some bicycles to the hotel. (PO-diff)

The cycling club leased the hotel some bicycles. (DO-same)

The cycling club rented the hotel some bicycles. (DO-diff)

The dealership leased a BMW to the newlyweds. (PO Target)

The dealership leased the newlyweds a BMW. (DO Target)

83 The junkyard shipped some damaged cars to the dealer. (PO-same)

The junkyard hauled some damaged cars to the dealer. (PO-diff)

The junkyard shipped the dealer some damaged cars. (DO-same)

The junkyard hauled the dealer some damaged cars. (DO-diff)

The charity shipped some coats to the homeless shelter. (PO Target)

The charity shipped the homeless shelter some coats. (DO Target)

84 The circus hauled a team of elephants to the zoo. (PO-same)

The circus shipped a team of elephants to the zoo. (PO-diff)

The circus hauled the zoo a team of elephants. (DO-same)

The circus shipped the zoo a team of elephants. (DO-diff)

The company hauled a crane to the oil rig. (PO Target)

The company hauled the oil rig a crane. (DO Target)

85 The quarterback tossed the football to the referee. (PO-same)

The quarterback threw the football to the referee. (PO-diff)

The quarterback tossed the referee the football. (DO-same)

The quarterback threw the referee the football. (DO-diff)

The trainer tossed a frisbee to the border collie. (PO Target)

The trainer tossed the border collie a frisbee. (DO Target)

86 The man threw some bread crumbs to the pigeons. (PO-same)

The man tossed some bread crumbs to the pigeons. (PO-diff)

The man threw the pigeons some bread crumbs. (DO-same)

The man tossed the pigeons some bread crumbs. (DO-diff)

The farmer threw some table scraps to the pigs. (PO Target)

The farmer threw the pigs some table scraps. (DO Target)

87 The assistant read a famous poem to me. (PO-same)

The assistant recited a famous poem to me. (PO-diff)

The assistant read me a famous poem. (DO-same)

The assistant recited me a famous poem. (DO-diff)

The father read a bedtime story to his son. (PO Target)

The father read his son a bedtime story. (DO Target)

88 The poet recited a verse to them. (PO-same)

The poet read a verse to them. (PO-diff)

The poet recited them a verse. (DO-same)

The poet read them a verse. (DO-diff)

The director recited a line to the actor. (PO Target)

The director recited the actor a line. (DO Target)

89 The embassy forwarded a message to the FBI. (PO-same)

The embassy wired a message to the FBI. (PO-diff)

The embassy forwarded the FBI a message. (DO-same)

The embassy wired the FBI a message. (DO-diff)

The officer forwarded the new orders to the regiment. (PO Target)

The officer forwarded the regiment the new orders. (DO Target)

90 The accountant wired a bill to the contractor. (PO-same)

The accountant forwarded a bill to the contractor. (PO-diff)

The accountant wired the contractor a bill. (DO-same)

The accountant forwarded the contractor a bill. (DO-diff)

The florist wired money to the supplier. (PO Target)

The florist wired the supplier money. (DO Target)

91 The professor taught a rule to the class. (PO-same)

The professor told a rule to the class. (PO-diff)

The professor taught the class a rule. (DO-same)

The professor told the class a rule. (DO-diff)

The executive taught the ethics policy to the employees. (PO Target)

The executive taught the employees the ethics policy. (DO Target)

92 The surgeon told the procedure to the intern. (PO-same)

The surgeon taught the procedure to the intern. (PO-diff)

The surgeon told the intern the procedure. (DO-same)

The surgeon taught the intern the procedure. (DO-diff)

The bartender told a clever joke to the waitress. (PO Target)

The bartender told the waitress a clever joke. (DO Target)

93 The governor left some land to the university. (PO-same)

The governor bequeathed some land to the university. (PO-diff)

The governor left the university some land. (DO-same)

The governor bequeathed the university some land. (DO-diff)

A lottery winner left his fortune to a complete stranger. (PO Target)

A lottery winner left a complete stranger his fortune. (DO Target)

94 A rich man bequeathed some money to his relatives. (PO-same)

A rich man left some money to his relatives. (PO-diff)

A rich man bequeathed his relatives some money. (DO-same)

A rich man left his relatives some money. (DO-diff)

The tycoon bequeathed nothing to his children. (PO Target)

The tycoon bequeathed his children nothing. (DO Target)

95 The player flashed a sign to his partner. (PO-same)

The player showed a sign to his partner. (PO-diff)

The player flashed his partner a sign. (DO-same)

The player showed his partner a sign. (DO-diff)

The teenager flashed a smile to her friend. (PO Target)

The teenager flashed her friend a smile. (DO Target)

96 The coach showed a new signal to the rookie. (PO-same)

The coach flashed a new signal to the rookie. (PO-diff)

The coach showed the rookie a new signal. (DO-same)

The coach flashed the rookie a new signal. (DO-diff)

The freshman showed his report card to his parents. (PO Target)

The freshman showed his parents his report card. (DO Target)

97 The stock broker bought a Rolls Royce for his mistress. (PO-same)

The stock broker purchased a Rolls Royce for his mistress. (PO-diff)

The stock broker bought his mistress a Rolls Royce. (DO-same)

The stock broker purchased his mistress a Rolls Royce. (DO-diff)

The man bought the roses for his wife. (PO Target)

The man bought his wife the roses. (DO Target)

98 The father purchased a baseball for his six-year-old. (PO-same)

The father bought a baseball for his six-year-old. (PO-diff)

The father purchased his six-year-old a baseball. (DO-same)

The father bought his six-year-old a baseball. (DO-diff)

The duchess purchased the lawnmower for the gardener. (PO Target)

The duchess purchased the gardener the lawnmower. (DO Target)

99 An inventor built a radio for his mother. (PO-same)

An inventor made a radio for his mother. (PO-diff)

An inventor built his mother a radio. (DO-same)

An inventor made his mother a radio. (DO-diff)

Habitat built a nice house for the refugees. (PO Target)

Habitat built the refugees a nice house. (DO Target)

100 The mechanic made the wheelchair for his brother. (PO-same)

The mechanic built the wheelchair for his brother. (PO-diff)

The mechanic made his brother the wheelchair. (DO-same)

The mechanic built his brother the wheelchair. (DO-diff)

Dad made a kitchen table for the family. (PO Target)

Dad made the family a kitchen table. (DO Target)

101 A guard found the keys for the prison warden. (PO-same)

A guard got the keys for the prison warden. (PO-diff)

A guard found the prison warden the keys. (DO-same)

A guard got the prison warden the keys. (DO-diff)

The woman found an apartment for her mother. (PO Target)

The woman found her mother an apartment. (DO Target)

102 A rock star got some cocaine for his manager. (PO-same)

A rock star found some cocaine for his manager. (PO-diff)

A rock start got his manager some cocaine. (DO-same)

A rock star found his manager some cocaine. (DO-diff)

A journalist got an interview for his editor. (PO Target)

A journalist got his editor an interview. (DO Target)

103 A secretary baked the casserole for her boss. (PO-same)

A secretary microwaved the casserole for her boss. (PO-diff)

A secretary baked her boss the casserole. (DO-same)

A secretary microwaved her boss the casserole. (DO-diff)

The pastry chef baked some pies for her friend. (PO Target)

The pastry chef baked her friend some pies. (DO Target)

104 The waitress microwaved a tray of appetizers for the customers. (PO-same)

The waitress baked a tray of appetizers for the customers. (PO-diff)

The waitress microwaved the customers a tray of appetizers. (DO-same)

The waitress baked the customers a tray of appetizers. (DO-diff)

The girl microwaved some popcorn for her brother. (PO Target)

The girl microwaved her brother some popcorn. (DO Target)

105 The librarian wrote a short story for the handicapped boy. (PO-same)

The librarian typed a short story for the handicapped boy. (PO-diff)

The librarian wrote the handicapped boy a short story. (DO-same)

The librarian typed the handicapped boy a short story. (DO-diff)

The servant wrote the shopping list for the cook. (PO Target)

The servant wrote the cook the shopping list. (DO Target)

106 The principal typed a letter of recommendation for the teacher. (PO-same)

The principal wrote a letter of recommendation for the teacher. (PO-diff)

The principal typed the teacher a letter of recommendation. (DO-same)

The principal wrote the teacher a letter of recommendation. (DO-diff)

The assistant typed a memo for the supervisor. (PO Target)

The assistant typed the supervisor a memo. (DO Target)

107 An artist drew a portrait for the police captain. (PO-same)

An artist sketched a portrait for the police captain. (PO-diff)

An artist drew the police captain a portrait. (DO-same)

An artist sketched the police captain a portrait. (DO-diff)

The illustrator drew a picture for the children's author. (PO Target)

The illustrator drew the children's author a picture. (DO Target)

108 An architect sketched a new logo for the company. (PO-same)

An architect drew a new logo for the company. (PO-diff)

An architect sketched the company a new logo. (DO-same)

An architect drew the company a new logo. (DO-diff)

The builder sketched the blueprints for the electrician. (PO Target)

The builder sketched the electrician the blueprints. (DO Target)

109 The grandmother sewed a cape for her granddaughter. (PO-same)

The grandmother knitted a cape for her granddaughter. (PO-diff)

The grandmother sewed her granddaughter a cape. (DO-same)

The grandmother knitted her granddaughter a cape. (DO-diff)

The designer sewed the dress for the movie star. (PO Target)

The designer sewed the movie star the dress. (DO Target)

110 Mom knitted the costume for me. (PO-same)

Mom sewed the costume for me. (PO-diff)

Mom knitted me the costume. (DO-same)

Mom sewed me the costume. (DO-diff)

The lady knitted a hat for the soldier. (PO Target)

The lady knitted the soldier a hat. (DO Target)

111 A woodcarver whittled the toy duck for the orphan. (PO-same)

A woodcarver carved the toy duck for the orphan. (PO-diff)

A woodcarver whittled the orphan the toy duck. (DO-same)

A woodcarver carved the orphan the toy duck. (DO-diff)

The hiker whittled a cane for the injured man. (PO Target)

The hiker whittled the injured man a cane. (DO Target)

112 The stepfather carved a boomerang for his stepson. (PO-same)

The stepfather whittled a boomerang for his stepson. (PO-diff)

The stepfather carved his stepson a boomerang. (DO-same)

The stepfather whittled his stepson a boomerang. (DO-diff)

The warrior carved some spears for the hunters. (PO Target)

The warrior carved the hunters some spears. (DO Target)

113 The woman stole a saw for her husband. (PO-same)

The woman fetched a saw for her husband. (PO-diff)

The woman stole her husband a saw. (DO-same)

The woman fetched her husband a saw. (DO-diff)

The ninja stole some weapons for the hostages. (PO Target)

The ninja stole the hostages some weapons. (DO Target)

114 The pimp fetched some drugs for the addict. (PO-same)

The pimp stole some drugs for the addict. (PO-diff)

The pimp fetched the addict some drugs. (DO-same)

The pimp stole the addict some drugs. (DO-diff)

The singer fetched a tape for the talent scout. (PO Target)

The singer fetched the talent scout a tape. (DO Target)

115 Laura prepared a duck for her guests. (PO-same)

Laura roasted a duck for her guests. (PO-diff)

Laura prepared her guests a duck. (DO-same)

Laura roasted her guests a duck. (DO-diff)

The parents prepared some sack lunches for the soccer team. (PO Target)

The parents prepared the soccer team some sack lunches. (DO Target)

116 Aunt May roasted a chicken for Sally. (PO-same)

Aunt May prepared a chicken for Sally. (PO-diff)

Aunt May roasted Sally a chicken. (DO-same)

Aunt May prepared Sally a chicken. (DO-diff)

Someone roasted the rack of lamb for the family. (PO Target)

Someone roasted the family the rack of lamb. (DO Target)

117 The caterers fixed a free banquet for the Lions Club. (PO-same)

The caterers cooked a free banquet for the Lions Club. (PO-diff)

The caterers fixed the Lions Club a free banquet. (DO-same)

The caterers cooked the Lions Club a free banquet. (DO-diff)

The choir fixed the refreshments for the church group. (PO Target)

The choir fixed the church group the refreshments. (DO Target)

118 The restaurant cooked a large dinner for the customer. (PO-same)

The restaurant fixed a large dinner for the customer. (PO-diff)

The restaurant cooked the customer a large dinner. (DO-same)

The restaurant fixed the customer a large dinner. (DO-diff)

Anne cooked a lunch for her closest friends. (PO Target)

Anne cooked her closest friends a lunch. (DO Target)

119 A cheerleader saved a seat for her friend. (PO-same)

A cheerleader reserved a seat for her friend. (PO-diff)

A cheerleader saved her friend a seat. (DO-same)

A cheerleader reserved her friend a seat. (DO-diff)

The bride saved some cake for her cousin. (PO Target)

The bride saved her cousin some cake. (DO Target)

120 A solider reserved a ticket for his pal. (PO-same)

A solider saved a bunk for his pal. (PO-diff)

A solider reserved his pal a ticket. (DO-same)

A solider saved his pal a bunk. (DO-diff)

The man reserved a nice table for himself. (PO Target)

The man reserved himself a nice table. (DO Target)

121 The music teacher sang a song for the class. (PO-same)

The music teacher played a song for the class. (PO-diff)

The music teacher sang the class a song. (DO-same)

The music teacher played the class a song. (DO-diff)

Janet sang her biggest hits for the fans. (PO Target)

Janet sang the fans her biggest hits. (DO Target)

122 The soloist played a hymn for the congregation. (PO-same)

The soloist sang a hymn for the congregation. (PO-diff)

The soloist played the congregation a hymn. (DO-same)

The soloist sang the congregation a hymn. (DO-diff)

A guitarist played the chords for his instructor. (PO Target)

A guitarist played his instructor the chords. (DO Target)

123 The manager fried some eggs for his cousins. (PO-same)

The manager boiled some eggs for his cousins. (PO-diff)

The manager fried his cousins some eggs. (DO-same)

The manager boiled his cousins some eggs. (DO-diff)

The graduate student fried some potatoes for his parents. (PO Target)

The graduate student fried his parents some potatoes. (DO Target)

124 Julie boiled some vegetables for the kids. (PO-same)

Julie cooked some vegetables for the kids. (PO-diff)

Julie boiled the kids some vegetables. (DO-same)

Julie cooked the kids some vegetables. (DO-diff)

The maid boiled some water for her mistress. (PO Target)

The maid boiled her mistress some water. (DO Target)

125 A lady wove a carpet for the newlyweds. (PO-same)

A lady stitched a carpet for the newlyweds. (PO-diff)

A lady wove the newlyweds a carpet. (DO-same)

A lady stitched the newlyweds a carpet. (DO-diff)

The godmother wove a tapestry for her goddaughter. (PO Target)

The godmother wove her goddaughter a tapestry. (DO Target)

126 The grandmother stitched the blanket for her grandchildren. (PO-same)

The grandmother wove the blanket for her grandchildren. (PO-diff)

The grandmother stitched her grandchildren the blanket. (DO-same)

The grandmother wove her grandchildren the blanket. (DO-diff)

The pregnant woman stitched some booties for her baby. (PO Target)

The pregnant woman stitched her baby some booties. (DO Target)

127 The guide sliced some jerky for the explorer. (PO-same)

The guide cut some jerky for the explorer. (PO-diff)

The guide sliced the explorer some jerky. (DO-same)

The guide cut the explorer some jerky. (DO-diff)

The woman sliced some peaches for her kids. (PO Target)

The woman sliced her kids some peaches. (DO Target)

128 The mother cut some steak for her son. (PO-same)

The mother sliced some steak for her son. (PO-diff)

The mother cut her son some steak. (DO-same)

The mother sliced her son some steak. (DO-diff)

The deli cut some smoked cheese for a customer. (PO Target)

The deli cut a customer some smoked cheese. (DO Target)

Highlights

- Compared structural persistence in language comprehension and production
- Used the same priming procedures, prime and target sentences, and participants
- Observed abstract and lexically boosted persistence in both modalities
- Standardized priming scores revealed similar amounts of persistence in both modalities
- Structural processes share basic properties in language production and comprehension

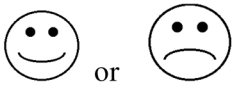
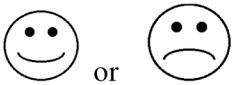
Timing	Prime Presentation	Target Presentation
200 ms	*********	*********
100 ms per word	Sentence presented one word at a time	Sentence presented one word at a time
100 ms	##########	##########
533 ms + 10 ms blank	2 7 9 4 1	8 1 2 4 5
500 ms + 10 ms blank	Seven	Nine
Stays on screen until left or right button is pressed	Yes No	Yes No
500 ms		
Stays on screen	Repeat	Repeat
Participant pushes space bar when finished repeating sentence	Participant repeats sentence	Participant repeats sentence
Stays on screen until left or right button is pressed	Same or Different	Same or Different

Figure 1.
Production priming procedure.

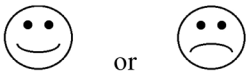
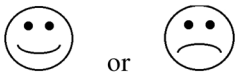
Timing	Prime Presentation	Target Presentation
200 ms	*********	*********
100 ms per word	Sentence presented one word at a time	Sentence presented one word at a time
100 ms	##########	##########
533 ms + 10 ms blank	2 7 9 4 1	8 1 2 4 5
500 ms + 10 ms blank	Seven	Nine
Stays on screen until left or right button is pressed	Yes No	Yes No
500 ms		
500 ms	Read	Read
self-paced reading of sentence	The ____ _ ___ __ _____ __ __.	A ____ _ ___ __ _____ __ __.
Stays on screen until left or right button is pressed	Same or Different	Same or Different

Figure 2.
Comprehension priming procedure.

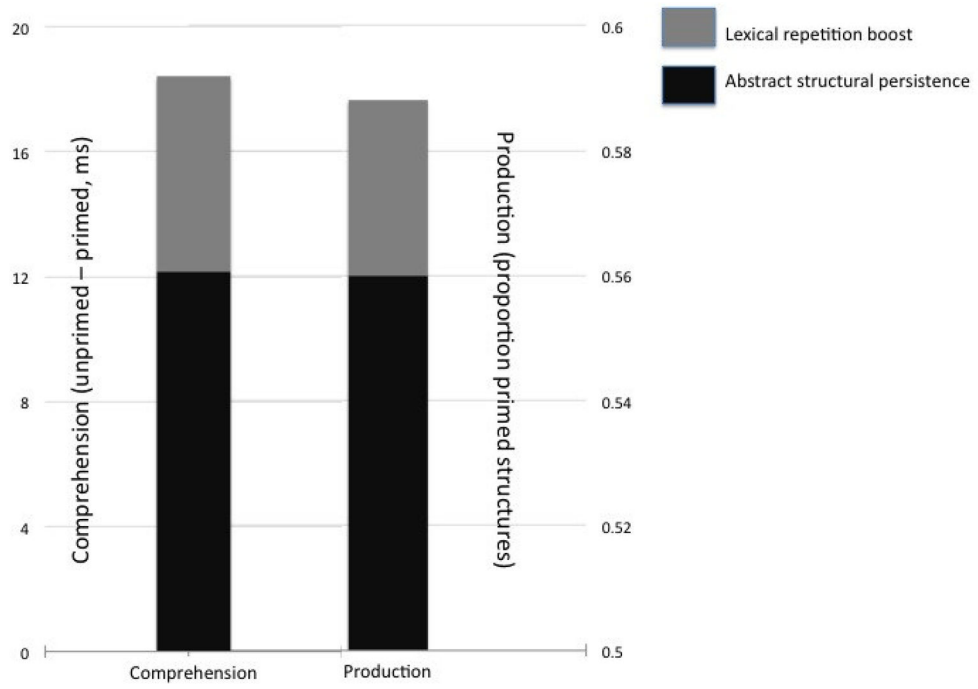


Figure 3.

Summary view of structural persistence in language comprehension and production when verbs in prime and target were not repeated (abstract structural persistence) and repeated (lexical repetition boost). Bar height is a raw estimate of total persistence.

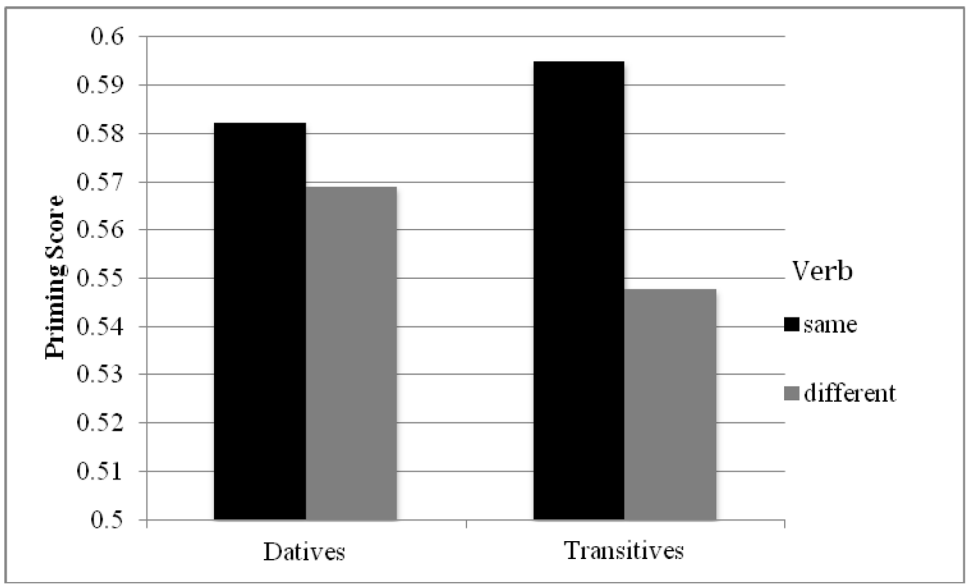


Figure 4.

Priming effects in production (proportion primed structures produced) for dative and transitive sentences with the same or different prime and target verbs.

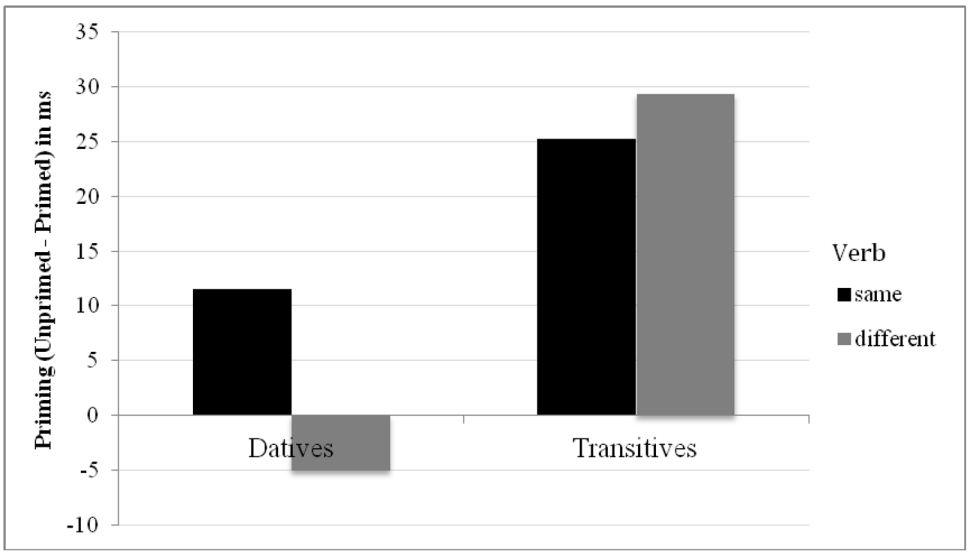


Figure 5.

Priming effect (unprimed – primed) for reading times in critical regions of dative and transitive target sentences with same or different verbs as primes.

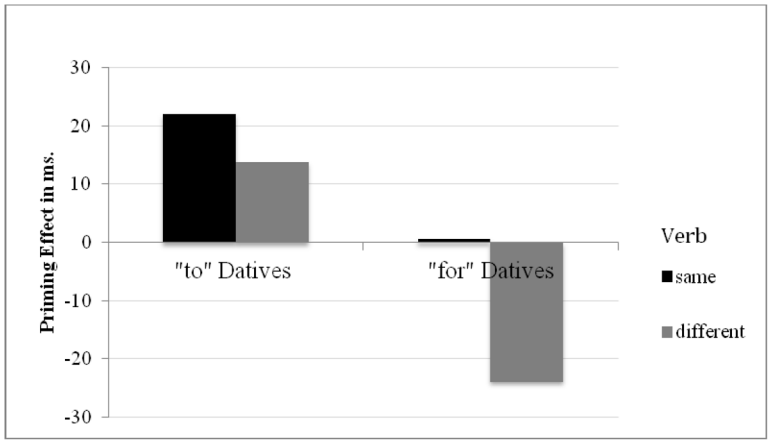


Figure 6.

Mean priming effects (Unprimed – Primed) for comprehending *to*- and *for*-dative sentences with same or different verbs in prime and target sentences.

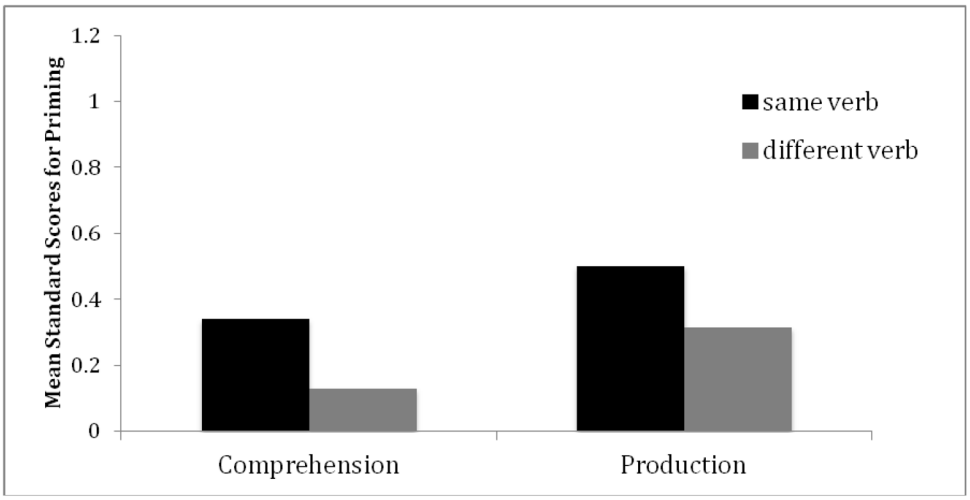


Figure 7.
Mean standard scores for priming effects (primed – unprimed) of equivalent items in comprehension and production

Table 1

Example of prime and target pairings for one transitive and one dative item in each priming condition.

Priming condition	Same or different verb	Prime or target sentence	Transitive structures	
			Main clause	**Reduced-relative clause**
Primed	Same	Prime	The nanny scrubbed the girl who was filthy.	The girl scrubbed by the nanny was filthy.
		Target	The nurse scrubbed the doctor who was prepping for surgery.	The doctor scrubbed by the nurse was prepping for surgery.
	Different	Prime	The nanny cleaned the girl who was filthy.	The girl cleaned by the nanny was filthy.
		Target	The nurse scrubbed the doctor who was prepping for surgery.	The doctor scrubbed by the nurse was prepping for surgery.
Unprimed	Same	Prime	The girl scrubbed by the nanny was filthy.	The nanny scrubbed the girl who was filthy.
		Target	The nurse scrubbed the doctor who was prepping for surgery.	The doctor scrubbed by the nurse was prepping for surgery.
	Different	Prime	The girl cleaned by the nanny was filthy.	The nanny cleaned the girl who was filthy.
		Target	The nurse scrubbed the doctor who was prepping for surgery.	The doctor scrubbed by the nurse was prepping for surgery.
			Dative structures	
			Prepositional object	Double object
Primed	Same	Prime	The junkyard shipped some damaged cars to the dealer.	The junkyard shipped the dealer some damaged cars.
		Target	The charity shipped some coats to the homeless shelter.	The charity shipped the homeless shelter some coats.
	Different	Prime	The junkyard hauled some damaged cars to the dealer.	The junkyard hauled the dealer some damaged cars.
		Target	The charity shipped some coats to the homeless shelter.	The charity shipped the homeless shelter some coats.
Unprimed	Same	Prime	The junkyard shipped the dealer some damaged cars.	The junkyard shipped some damaged cars to the dealer.
		Target	The charity shipped some coats to the homeless shelter.	The charity shipped the homeless shelter some coats.
	Different	Prime	The junkyard hauled the dealer some damaged cars.	The junkyard hauled some damaged cars to the dealer.
		Target	The charity shipped some coats to the homeless shelter.	The charity shipped the homeless shelter some coats.

Table 2

Counts of dative and transitive sentences produced in the primed structure with and without verb overlap (same or different verb in prime and target)

		Verb overlap	
Sentence type	**Priming**	**Same**	**Different**
Datives	Primed	591	527
	Unprimed	424	399
Transitives	Primed	498	378
	Unprimed	339	312

Table 3

Model predictions of structure produced, estimated from priming and verb overlap

Effect	Beta	*p*-value	Standard error
		Both sentence types	
Intercept	0.21	< 0.0001	0.034
Priming	−0.18	< 0.01	0.068
Verb Overlap	0.055	0.42	0.068
Priming X Verb Overlap	0.14	0.30	0.14
AIC = 4835			
		Transitives	
Intercept	−0.15	0.0027	0.051
Priming	0.21	0.035	0.10
Verb Overlap	−0.11	0.27	0.10
Priming X Verb Overlap	−0.13	0.55	1.21
AIC = 2163			
		Datives	
Intercept	0.25	< 0.0001	0.046
Priming	−0.15	0.092	0.091
Verb Overlap	0.013	0.89	0.091
Priming X Verb Overlap	0.15	0.40	0.18
AIC = 2717			

Table 4

Mean reading times in ms for the verb region, critical region, and spillover region in the target sentences, broken down by structure, priming condition, and verb overlap (verb same or different)

		Sentence region					
		Verb region		Critical region		Spillover region	
Sentence type	Priming	Same verb	Different verb	Same verb	Different verb	Same verb	Different verb
Dative	Primed	313	327	715	719	802	800
	Unprimed	327	319	727	714	791	797
Transitive	Primed	322	326	792	808	726	726
	Unprimed	321	333	817	837	731	742

Table 5

Model estimates of reading times on comprehension trials at the critical region for sentence types combined and for transitives and datives separately

	Beta	*p*-value	Std. error
	Both sentence types		
Intercept	768.93	< 0.0001	14.12
Priming	16.70	0.013	6.84
Verb Overlap	−4.62	0.46	6.57
Priming X Verb Overlap	10.76	0.42	13.14
AIC = 106559			
	Transitives		
Intercept	815.80	< 0.0001	15.09
Priming	30.53	0.0015	9.78
Verb Overlap	−11.88	0.2	9.62
Priming X Verb Overlap	8.11	0.69	19.00
AIC = 54003			
	Datives		
Intercept	721.48	< 0.0001	15.06
Priming	2.56	0.73	9.88
Verb Overlap	2.41	0.75	9.84
Priming X Verb Overlap	16.65	0.36	18.84
AIC = 52818			

Table 6

Means of standardized production and comprehension scores for primed and unprimed target sentences with prime-same or prime-different verbs

	Primed		Unprimed	
	Same verb	**Different verb**	**Same verb**	**Different verb**
Production	.36	.04	−.14	−.27
Comprehension	.17	.07	−.17	−.06

Table 7

Summary of results from analysis of variance on standardized production and comprehension scores

Source	Degrees of freedom	MSE	*F*	*P*
Priming	1,127	1.30	20.26	<.001
Verb Overlap	1,127	.19	16.22	<.001
Modality	1,127	1.36	<1	.99
Priming x Verb Overlap	1,127	.93	2.73	.10
Priming x Modality	1,127	1.41	1.35	.25
Verb Overlap x Modality	1,127	.20	17.29	<.01
Priming x Verb Overlap x Modality	1,127	1.07	<1	.93