Are syntactic representations similar in both reading and listening? Evidence from priming in first and second language.

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Abstract

It is unclear to what extent natural differences between reading and listening might result in differences in the syntactic representations formed in each modality. The present study investigated the occurrence of syntactic priming bi-directionally from reading to listening, and vice versa to examine whether reading and listening share the same syntactic representations. English first (L1) and second language (L2) speaker participants performed a lexical decision task (LDT) in which final words were embedded in sentences with either ambiguous or familiar structure. These structures were alternated to produce a priming effect. The modality was manipulated whereby participants a) firstly read part of the sentence list, and then listened to the rest of the list (reading-listening group), or b) listened and then read (listening-reading group). In addition, the study involved two within-modality lists in which participant either read or listened to the whole list. L1 group showed within-modal priming in both listening and reading in addition to cross-modal priming. Although L2 speakers showed priming in reading, the effect was absent in listening and weak in the listening-reading condition. The absence of priming in L2 listening was attributed to difficulties in L2 listening rather than an inability to produce abstract priming.

Keywords: syntactic priming, second language, cross-modality effect

1. Introduction

1.1. Syntactic Priming

Syntactic priming in comprehension refers to a facilitation in the processing of a sentence (target sentence) following the processing of a preceding unrelated sentence(s) (prime sentence) that share the same syntactic structure (for reviews, see Pickering & Ferreira, 2008; Tooley & Traxler, 2010). For example, language users process an ambiguous modifier prepositional phrase (PP) as in "*The girl hit the boy with the bruise earlier today*" more easily following exposure to another modifier PP such as "*The worker fixed the wall with a hole*" than following a non-modifier PP as in "*The worker fixed the wall with a tape*". Such facilitation effects have been demonstrated extensively in behavioral measures via faster reading times (Traxler, Tooley, & Pickering, 2014), anticipatory eye movements (Arai, Van Gompel, & Scheepers, 2007), and biased choices of pictures that correspond to ambiguous sentences (Branigan, Pickering, & McLean, 2005). It has also been shown in neural networks using EEG. The priming effect was evident in the reduced amplitudes of the P600 (ERP related to syntactic anomalies) (Ledoux, Traxler, & Swaab, 2007; Tooley, Traxler, & Swaab, 2009).

Syntactic priming effect has been detected cross-modally across production modalities (i.e., from speaking to writing and from writing to speaking) (Cleland and Pickering, 2006). In comprehension, syntactic priming was found from reading to listening in L1 in studies which employed a visual world paradigm to examine priming in dative constructions (Arai, van Gompel & Scheepers, 2007; Carminati, van Gompel, Scheepers & Arai, 2008; Scheepers & Crocker, 2004; Thothathiri & Senedeker, 2008). For example, Arai et al., (2007) conducted a study in which participants first read a prime sentence, and then listened to a target sentence in either a prepositional object dative structure as in "*the pirate will send the necklace to the* *princess"* or a double object dative structure as in "*the pirate will send the princess the necklace"*. Target sentences were presented with pictures that depict the three referents in the sentence (e.g., a picture of a pirate, a princess, and a necklace). Participants' eye movements were recorded upon hearing the verb in the target (i.e., "*will send*"). Results showed that participants were more likely to gaze anticipatorily at the princess after having read a double object prime aloud, but more likely to gaze at the necklace after having read a prepositional object prime. Findings from the visual world paradigm, therefore, showed the occurrence of a priming effect that transferred from reading to listening. Nevertheless, the opposite direction (i.e., from listening to reading) has not yet been investigated. Furthermore, cross-modal priming has yet to be investigated in L2 speakers.

A mode of syntactic priming that has been studied within-modally is the cumulative priming paradigm (Fine & Jaeger, 2013; Fine & Jaeger, 2016; Fine, Qian, Jaeger &Jacobs, 2010; Kaschack & Glenberg, 2004; Wells, Christiansen, race, Acheson & MacDonald, 2009) in which participants gradually adapt to an unfamiliar structure after repeated exposure to several instances of that structure. This syntactic adaptation is backed by a statistical learning account in which language user store information about the probability of occurrence of the encountered syntactic features (Kleinschmidt, Fine & Jaeger, 2012; Kleinschmidt & Jaeger, 2015). When exposed to a new context with different probabilities, language users dynamically employ statistical learning mechanisms to update their knowledge, preferences and predictions according to the probabilities of the new context. Syntactic structures that are more frequently encountered are assigned higher probability and subsequently become more predicted and preferred. For example, repeated exposure led listeners to adapt to syntactic structures that were initially judged as ungrammatical to the extent that they became more easily processed (Luka & Barsalou, 2005) and even produced (Kaschak & Glenberg, 2004).

Studies employing the artificial grammar learning paradigm demonstrated that the ability to extract probabilistic information from the environment is modality-specific (Conway & Christiansen, 2005; Conway & Cristiansen, 2006; Li, Zhao, Shi, Lu and Conway, 2018; Redington & Chater, 1996). Learning a grammatical structure in one modality cannot therefore be transferred to a different modality. For example, Conway and Christiansen (2006) exposed participants to visual color sequence generated from one grammar and auditory tone sequence generated from another grammar. Whilst both modalities were presented simultaneously in the training phase, only one modality was employed in the testing phase. Participants couldn't generalize the grammar learnt through one modality in the training phase to the different modality in the test phase. Thus, results showed that statistical learning is modality-specific. Given that the cumulative priming paradigm depends on statistical learning of the syntactic probabilities in the linguistic environment, it can be predicted that the cumulative priming effect cannot transfer across different comprehension modalities. Nevertheless, Tunney and Altmann (2001) argued that the modality-specific episodic repeated fragments employed in artificial grammar paradigm studies differ from the modality-independent transitional probability that characterizes statistical learning in language. This lack of consensus necessitates a further investigation of the cross-modal transfer.

1.2. Differences between reading and listening

The dissociation in syntactic processing between listening and reading is supported by the neuropsychological studies in which aphasic patients maintain their visual orthographic ability in the presence of a dysfunctional oral phonological system and vice versa. Tyler, Moss, & Jennings (1995) found deficits in verbal, but not oral, production of abstract words among deep dyslexic patients. In addition, Endo, Makishita, Yanagisawa and Sugishita (1996) observed deficits in performing visual naming task as compared to auditory naming in aphasia. At the level of syntax, Caramazza and Hillis (1991) examined the production of nouns vs. verbs in two neurologically impaired patients, HW and SJD. HW made more errors on verbs than on nouns in oral but not in written output; whereas, SJD showed the same verb production deficit in writing, but not in speech. In a subsequent study, Hillis and Caramazza (1995) found that a neurologically impaired patient, EBA, showed more impairment in noun production in oral than in written output but more impairment in recognizing and comprehending written verbs than oral verbs. These results indicate a dissociation between the oral and written modalities with regard to the production and processing of word grammatical category (i.e., nouns vs. verbs).

At the sentence level, comprehension involves integrating the incoming words into the sentence context through combining semantic, syntactic and pragmatic sources of information in both bottom-up and top-down manner. One can expect sentence integration to be similar in both listening and reading due to the same semantic, syntactic, and pragmatic roles being employed in both modalities. For example, language users who show high proficiency in reading comprehension are more likely to be highly proficient in listening comprehension (Protopapas, Simos, Sideridis & Mouzaki, 2012; Tilstra, McMaster, Van Den Broek, Kendou & Rapp, 2009; Townsend, Carrithers, & Bever, 1987). Nevertheless, there are some modality-specific characteristics that might result in differences in the representation resulting in each modality. For example, in reading the entire discourse is simultaneously present, meaning that the reader might retreat back at any point to the beginning of the sentence, whereas listening disappears instantaneously, so listeners cannot backtrack. Accordingly, there is evidence that monolingual listeners tend to perform shallow and partial syntactic processing to be able to keep up with the rapidly incoming linguistic input in listening as opposed to reading (Christianson, Hollingworth, Halliwell, & Ferreira, 2003; Ferreira, Christianson, & Hollingworth, 2001).

1.3. Syntactic priming in L2

Comprehension cumulative priming in L2 has been studied in one reading study (Kaan et al., 2018), which is far less often than in L1. Kaan et al., (2018) employed a self- paced reading task to examine accumulative adaptation to two types of syntactic ambiguity by both native and non-native English speakers. The two ambiguous structures tested were filled-gap constructions in *wh*-clauses as in (*the builder wondered what the worker repaired the leak with before going home*), and coordination ambiguity as in (*the servant cleaned the table and the floor was cleaned by the maid*). Only native speakers showed accumulative adaptation. It can, therefore, be inferred that L2 processing is not sensitive to the statistical learning mechanisms underlying cumulative priming in reading; however, previous evidence is very limited. No L2 cumulative priming research has been conducted in the listening modality. Therefore, Further studies are needed to gain robust relevant conclusions.

Nevertheless, studies that used modes of syntactic priming that differ from the cumulative paradigm showed that syntactic priming is stronger in L2 than in L1 in both listening (Nitschke, Serratrice, and Kidd, 2014; Nitschke, Kidd, and Serratrice, 2010) and reading (Wei et al., 2017, 2019). L2 advantage was accounted for by Pickering and Branigan (1999) who suggested that priming is a function of limited resources. L2 speakers who naturally possess limited cognitive resources are more likely to be susceptible to priming than L1 speakers who are more experienced with the language, and therefore store alternatives of the appropriate structure. These alternatives may suppress the effect of the prime sentence. The greater magnitude of priming in L2 can also be accounted for by the inverse frequency effect. The inverse frequency effect refers to the common finding that syntactic structures occurring relatively infrequently tend to produce greater priming than more frequent structures (Ledoux et al., 2007; Scheepers & Crocker, 2004; Sturt, Keller, & Dubey, 2010; Traxler et al., 2014;

Traxler, 2008). Generally, L2 speakers have limited experience with linguistic regularities resulting from their less frequent encounter with L2 syntactic structures, which might be the reason for the greater syntactic priming effect in L2.

However, it can be predicted that L2 speakers might face more difficulty in listening than in reading due to the temporal constraint imposed in listening. In real life, the speech stream flows spontaneously at the talker's pace. In contrast, reading is self-paced. The speed of the aural input might cause the mental resources to barely suffice the processing of the bottom-up signal at the expense of the syntactic integration process. Previous evidence showed shallow syntactic processing among L2 speakers when performing temporally constrained online tasks (Clahsen & Felser, 2006). This shallow processing causes over reliance on semantic, rather than syntactic, representation in sentence online processing (Felser, Roberts, Marinis, & Gross, 2003; Guo, Guo, Yan, Jiang, & Peng, 2008; Papadopoulou & Clahsen, 2003). Similarly, the timing constraints involved in the listening condition in the current study, similar to real life, might lead L2 listeners to rely on semantic features in the sentence and subsequently become more resistant to syntactic priming.

1.4. The present study

The aim is to investigate whether the priming produced in each of the listening or reading modalities would transfer to the other modality in both L1 and L2 speakers. To achieve this, the present study employed a cumulative priming paradigm in which the first 80% of the experimental sentences acted as primes, whereas the last 20% of sentences presented in the experimental setting acted as targets on which the priming effect was assessed. In the cross-modal priming from reading to listening condition, the prime sentences were read, and the targets were listened to, whereas in the opposite listening to reading condition the prime sentences were listened to and the target sentences were read.

Although cumulative priming has been shown to occur within-modally in both listening and reading, there is evidence that the statistical learning mechanism underlying the priming effect is modality-specific. As for L2 speakers, difficulties associated with listening might hinder the occurrence of syntactic adaptation in listening, and subsequently from listening to reading, but not in reading and from reading to listening. Another possibility is that L2 speakers might tend to exploit the grammatical knowledge resulting from syntactic priming to mediate listening difficulties. Syntactic priming in this case would disambiguate the speech signal and guide the processor's analysis to match the syntactic probabilities of the context, leading to the occurrence of priming in listening and from listening to reading similar to in reading and from reading to listening. The absence of priming in both reading and listening would indicate that L2 speakers are less able to adapt to the syntactic probabilities of the context irrespective of the modality.

Experiment 1: Cross-modal priming in L1

The aim is to examine whether the processing of an ambiguous structure in one modality (reading or listening) would lead to a facilitation in the processing of the same structure in the other modality in L1. To achieve this, the processing of target sentences like (1a, see below) will be assessed after exposure to multiple sentences of the same structure.

1a. The man fixed the box with a hole (low-attachment structure (LA))
1b. The apprentice fixed the mirror with a tape (high-attachment structure (HA))

In this type of structure, the PP can either be a modifier of the preceding noun as in (1a) "with a hole" or an instrument of the verb as in (1b) "with a tape". Being less familiar, the low-attachment structure as in (1a) causes processing difficulty when the perceivers incorrectly analyze the PP as an instrument of the verb (Rayner, Carlson, & Frazier, 1983)

Previous research demonstrated that this ambiguous low-attachment structure produces a syntactic priming effect that facilitates target sentence comprehension both in listening (Branigan, Pickering, & McLean, 2005) and reading (Boudewyn, Zirnstein, Swaab, & Traxler 2014; Traxler, 2008). The high-attachment as in (1b) was used as a control (baseline) to produce a no priming condition to which the processing of the ambiguous low-attachment structure can be compared.

In the present study, all low-attached prepositional phrases (PPs) carry an attribute semantic role “with a hole”, whereas, the high-attached PPs carry an instrument semantic role “with a tape”. The semantic role was unified across the experimental sentences for each structure because previous evidence suggests that the semantic role of the prepositional phrase biases the parsing of the pp attachment structure (Taraban & McCleland, 1988).

2.1. Method

2.1.1. Participants

The study included 80 participants who were between 18-23 (M = 19.2) years of age from the student cohort at the University of Leeds. All reported normal vision and hearing, and no neurological impairment. They were all native English speakers and formed the L1 group. Participants provided written informed consent. The experiment was reviewed and approved by the University of Leeds Research Ethics Committee (no.17-0098).

2.1.2. Materials

Participants were assigned to one of four lists; (i) two within-modality lists and (ii) two cross-modality list.

The two **within-modality lists** were: 1) a reading list, and 2) a listening list. In the within-modality lists, thirty sentences were constructed from six verbs. Fifteen sentences were in the low-attachment attribute modifier PP structure, and the other fifteen were in the high-attachment instrument PP counterpart structure. The two sentence structures were alternated over five similar blocks, resulting in six sentences per block, three in the low-attachment PP structure and three in the high-attachment PP structure. The order of presentation of the blocks was randomized across five lists. Two versions of each list were created to counterbalance sentence structure so that a low-attached PP sentence in one list version appeared as a VP-attached PP sentence in the other.

The two **cross-modality lists** were: 1) a reading - to - listening list in which participants read the first four blocks of the list and listened to the fifth block, and 2) a listening - to - reading list in which participants listened to the first four blocks and read the fifth. Similar to the within-modality list, the cross-modality list included 30 experimental sentences with the first four blocks consisting of 24 sentences and the fifth block containing 6 sentences. Each block contained 3 sentences in each of the two employed structures, resulting in fifteen sentences in the low-attachment structure and fifteen in the high-attachment structure. The order of blocks was randomized so five cross-role lists were created in which the last block included sentences that replicated those in the last block in each of the five within-role lists. Two versions of each list were created to counterbalance sentence structure so that a low-attached PP sentence in one list version appeared as a high-attached PP sentence in the other.

In addition to the experimental sentences, 10 word and 40 non-word filler sentences intervened between the prime and target sentences. The filler sentences are of randomly chosen structures and occupied different positions in the list for each participant. For the purposes of the lexical decision task, some of the filler sentences ended with a non-word. Non-words were generated using a stimulus generation program created by the English lexicon project (Balota et al., 2007). Non-words were matched with real words with respect to mean word length and mean bigram frequency. Six practice items were presented at the start of the experimental session to allow participants to practice the task and ask questions about the procedure. Each experimental or filler sentence was followed by a yes/no comprehension question. Comprehension questions were inserted to prevent the participants from directing their attention solely to the sentence final critical word instead of the whole sentence, which would have hardened the accumulation of the syntactic priming effect across the sentence list. For most of the question, the correct answer didn't require from the participants to resolve the syntactic ambiguity in question. This was done to obscure the main aim of the study so that any resulting facilitation in processing can be attributed to the implicit priming effect rather that the participants' explicit memory of the experimental stimul. See Appendix S1 for a full set of experimental and filler items.

The predictability of the final word in the sentence was controlled for by a cloze test. The cloze test was a sentence completion task in which all the experimental sentences were presented with the final critical words replaced with a gap. Twenty participants (who were all L1 speakers) were asked to fill in the gap with the first word that comes to mind. The experimental words produced an average cloze probability of 2.3% (range 0% - 5%), indicating none of the words were particularly predictable. To control for the lexical characteristics of the target words, the two groups of words embedded in each of high-attachment and low-attachment structure sentences were matched with respect to response time latency values that were extracted from the British Lexicon Project (Keuleers, Lacey, Rastle, & Brysbaert, 2012).

2.1.3. Procedure

The stimuli in this experiment were presented by the use of DMDX (Forster & Forster, 2003). A female speaker with a standard British English accent recorded the listening stimuli using Audacity software. Both LA and HA sentences were recorded using a neutral intonation such that a stop before the preposition phrase was avoided to prevent bias to the HA structure. Each subject was tested individually in a silent room. Participants were instructed to listen to or read the sentences and to state whether the last word was a real word or a non-word by pressing one of two keys. In the reading trials, a fixation point first appeared for 500 ms on the screen at the same place where the first letter of the sentence appeared. Participants were instructed to keep their fingers on the buttons at all times to encourage quick responding. The 'yes' response key was always pressed with the dominant hand and the 'no' response with the non-dominant hand. After that, sentence context up to the word preceding the final word appeared for 3000 ms with the position of the final target word marked with dashes. The 3-second presentation time was identified through a pilot study in which ten native English speakers were asked to read for comprehension all of the experimental sentences up till the final word. The reading times were calculated and averaged across sentences for each reader and across readers. Immediately after the sentence context disappeared from the screen, the final target word was displayed for 1000 ms. In the listening trials, a fixation point appeared on the screen for 500 ms before the sentence was presented via headphones. The speech rate was 140 wpm. In both listening and reading trials, participants were given 2500 ms to give a response. Response time was measured by DMDX from the onset of the target word. Following both reading and listening trials, the probe 'Question' was displayed for 500 ms, then the comprehension question was presented visually in a reading trial and orally in listening. Participants were allowed 2500 ms to answer the comprehension question.

2.2. Results

Erroneous responses, reaction times less than 100 ms and greater than 2000ms and data from sentences after which participants responded incorrectly to the comprehension question were all excluded from the analysis, resulting in the overall elimination of 12.6%, 18.3%, 13.5%, 17.5% of the data for the reading, reading to listening, listening and listening to reading groups respectively.

2.2.1. Within-modal priming

Repeated exposure to the ambiguous low-attachment structure throughout the list was expected to lead to a cumulative priming effect that would eliminate the processing difficulty towards the end of the list. This would result in critical words in sentences in the later blocks to be more easily processed than in sentences occurring earlier in the list. The effect is predicted to be observed in the ambiguous low-attachment structure rather than its familiar high-attachment counterpart. To assess the occurrence of such within-modal cumulative priming effect, error rates and RTs were analyzed using logit/linear mixed effects models calculated in R (R Development Core Team, 2008) using the lme4 package with random intercepts and slopes (Baayen, Davidson, & Bates, 2008). Both dependent measures were regressed onto the main effects and interactions of sentence structure (high- attachment vs. low-attachment), and block order (from 1-5). To control for task adaptation, log transformed stimulus order was also included as a predictor representing item position among other experimental, filler, and practice items (Fine et al., 2013). The difference between block order and stimulus order is that block order is a predictor of the occurrence of syntactic priming as exposure to more experimental items throughout the list is predicted to produce the priming effect in late blocks compared to early blocks; whereas, stimulus order is a predictor of the increased speed of processing resulting from increased adaptation to the task throughout the list (i.e., learning/training effect). Maximum random effects structure justified by the data was included. The best fitting random effect structure was determined by beginning with the maximal version of the model. If the maximal model wouldn’t show convergence, random effects were eliminated based on their variance such that random effects causing the least variance were removed first until the model reached convergence[1]. Although accurate responses to the comprehension question are not used as a dependent variable in the current experiments, comprehension question response accuracy was analyzed to give insight into the participants overall performance and the task level of difficulty. Accuracy scores are provided in Table S1 (Appendix 2 in Supplementary Materials). Comprehension questions accuracy data showed a main effect of block order in listening (β = 0.34, *SE*= 0.1454, z = 2.39, p = 0.016). Questions in the last block were answered more accurately than in the first block ($p < .05$). No main effects or interaction were found in reading.

Error rates results of the reading condition revealed a main effect of stimulus order (β = 2.99, *SE*= 1.43, z = 2.08, $p < .05$). Crucially, error rates revealed no interaction between structure and block order in both reading (β = 0.06, *SE*= 0.31, z = 0.2, p = .8) and listening (β = 0.02, *SE*= 0.37, z = 0.07, p = .9). All items were responded to with equal accuracy throughout the whole list, indicating the absence of within-modal priming effect in both reading and listening.

As for RT data analysis, the reading condition revealed a main effect of structure (β = 216.74, *SE*= 43.17, t = 5.02, $p < .001$) and stimulus order (β = -201.70, *SE*= 93.14, t = -2.1, $p < .05$). Crucially, there was an interaction between structure and block order (β = -63.63, *SE*= 12.79, t = -4.9, $p < .001$), whereby LA items in the first block elicited longer reaction times than LA items in the third ($p < .05$), fourth ($p < .001$), and fifth ($p < .001$) blocks. In listening, there was a main effect of structure (β = 208.59, *SE*= 50.71, t = 4.1, $p < .001$). In addition, there was an interaction of structure and block order (β = -60.52, *SE*= 13.6, t = -4.4, $p < .001$), with post-hoc comparisons revealing that LA sentences in the first block elicited slower response times than sentences occurring in the third block ($p < .01$), fourth block ($p < .05$), and fifth block ($p < .001$). This indicates the occurrence of within-modal cumulative priming in both reading and listening. Model estimates are presented in Table 1.

2.2.2. Cross-modal priming

Given that syntactic priming in the within-modal list was not evident by error rates data, this dependent measure is excluded from the analysis conducted to examine cross-modal priming. To examine the transfer of the syntactic priming effect across different modalities (i.e. from listening to reading and vice versa), we compared RTs in the last blocks for the within-modal versus the cross-modal lists. If the critical words in the sentences included in the fifth block are processed at equal speeds in both lists, this would indicate that a syntactic priming effect was transferred from the modality of the first four blocks, to the different modality of the fifth block in the cross-modal list.

Fixed effects in the structure of the regression model included group (cross-modal vs. within-modal), structure (LA vs. HA) and the interaction between group and structure. The model included maximal random effects structure justified by the data [2]. To examine the occurrence of priming from listening to reading, reaction times in the last block were compared between the within - and the cross - modal groups. Results revealed no group x structure interaction ($\beta = -80.23$, $SE = 82.39$, $t = -0.9$, $p = .3$) as LA items in the fifth blocks of both the listening-reading list (i.e., reading block) and the reading list elicited equal reaction times, indicating the occurrence of cross-modal priming from listening to reading (see Figure 1). Similarly, comparing reaction times in the last (listening) block between the listening and the reading to listening groups revealed no group by structure interaction ($\beta = -38.66$, $SE = 64.47$, $t = -0.60$, $p = .5$), indicating the occurrence of cross-modal priming from reading to listening (see Figure 2).

Cross-modal priming was additionally examined by comparing the fifth block of the cross-modal list to the first block of the within-modal list. A significant difference in processing between the two blocks would indicate that a priming effect was accumulated throughout the cross-modal list leading sentences in the last block to be more easily processed than in the first block of the within-modal list. Another model was fit including the main effects and interaction of sentence structure (LA vs. HA) and group (5^{th} block of cross-modal list vs. 1^{st} block of within-modal list). To examine the occurrence of priming from listening to reading, reaction times in the last (reading) block of the listening-reading list were compared to reaction times in the first block of the reading list. There was a main effect of structure, (β = 138.45, *SE*= 50.40, t = 2,74, $p < .01$). In addition, there was a main effect of group, (β = -127.03, *SE*= 56.50, t = -2.24, $p < .05$), whereby sentences appearing in the first block processed less rapidly (i.e., with higher reaction times) than items appearing in the final block. Additionally, there was an interaction (β = -188.23, *SE*= 72.03, t = -2.6, $p <.001$). LA items in the final reading block of the listening-to-reading list were processed more rapidly than items of the same structure in the first block of the reading list, which strengthens the evidence supporting the occurrence of cross-modal priming from listening to reading (see Figure 1).

To examine cross-modal priming from reading to listening, reaction times were compared for the fifth block (listening block) of the cross-modal reading-to-listening list and first block of the within-modal listening list, which revealed an interaction (β = 208.08, *SE*= 77.21, t = 2.69, $p <.01$). LA sentences in the fifth block (listening block) of the cross-modal list were processed more easily than LA sentences in first block of the within-modal listening list. This indicates the occurrence of cross-modal priming from reading to listening (see Figure 2).

To ensure that the cross-modal results can be attributed to the priming effect and not to the general differences in lexical decision between the tested groups. Separate analyses were conducted for each condition in the above cross-modal data analyses using reaction times and error-rates to filler items as dependent variables. Although error rates couldn't act as a dependent variable in the main analysis, it was used in this filler complementary analysis to give extra insight about any potential group differences that didn't stem from the priming effect. Linear/logit mixed effects models were fit including group as a fixed variable (last block of the cross-modal list group vs. last block of the within modal list group) or (first block of the within-modal list group. last block of the cross-modal list group). The model had maximal random effects structure justified by the data. Separate analyses were conducted for word and non-word items.

Word filler items data revealed no differences between the last blocks of the within-modal vs. cross-modal lists in reading reaction time (β = -76.96, *SE*= 93.22, t = -0.82), listening reaction time (β = -24.41, *SE*= 76.45, t = -0.319), reading error rates (β = 0.265, *SE*= 0.731, z = 0.363), and listening error rates (β = 0.164, *SE*= 0.573, z = 0.286). Additionally, no differences were revealed between the first block in the within-modal vs the last block in the cross-modal condition in reading reaction time (β = -199.9, *SE*= 128.0, t = -1.56), listening reaction time (β = 27.11, *SE*= 61.96, t = 0.43), reading error rates (β = 0.47, *SE*= 0.69, z = 0.67) and listening error rates (β = 0.64, *SE*= 0.67, z = -0.96).

Similarly, non-word filler items data revealed no differences between the last blocks of the within-modal vs. cross-modal lists in reading reaction time (β = 60.92, *SE*= 43.37, t = 1.40), listening reaction time (β = 96.06, *SE*= 58.89, t = 0.78), reading error rates (β = 0.43, *SE*= 0.47, z = 0.91), and listening error rates (β = 0.48, *SE*= 0.63, z = 0.75). No differences were revealed between the first block in the within-modal vs the last block in the cross-modal condition in reading reaction time (β = -119.39, *SE*= 66.27, t = -1.80), listening reaction time

($\beta = 31.44$, $SE = 44.65$, $t = 0.70$), reading error rates ($\beta = 0.23$, $SE = 0.48$, $z = 0.48$) and listening error rates ($\beta = 0.55$, $SE = 0.47$, $z = 1.15$).

Experiment 2: Cross-modal priming in L2

The aim of Experiment 2 is to examine whether syntactic priming in either listening or reading can transfer to the other modality in L2. The answer to this question will indicate whether syntactic priming in L2 comprehension can be a shared mechanism between reading and listening.

3.3. Method

3.3.1. Participants

Eighty native Arabic speakers with English as a second language participated in Experiment 2 and formed the L2 group of the study. Participant ages ranged from 17 to 33 years (M = 21.6 year). All participants reported normal to corrected hearing and vision, and no neurological impairments. Participants responded to a language history questionnaire prior to participation. All participants started to learn English between the ages 8 and 12 and were exposed to English in media and textbooks on a daily basis. Fifty-two participants (65%) lived in L1-dominant environment. All participants were either undergraduate or postgraduate students and had the minimum English proficiency required for enrollment in the University of Leeds with an IELTS (International English Language Testing System) total score of 6 out of 8 and a TOEFL (Test of English as a Foreign Language) score of 87 out of 120. Five students were enrolled in English language courses in the University of Leeds to further improve their language ability. Table 2 presents self-rated proficiency in English for the L2 group. Participants provided written informed consent. The experiment was reviewed and approved by the University of Leeds Research Ethics Committee (no.17-0098).

3.3.2. *Material and procedure*

Stimulus, materials, and procedures were the same as in Experiment 1.

3.4. Results

Erroneous responses, reaction times less than 100 ms and greater than 2000ms and data from sentences after which participants responded incorrectly to the comprehension question were all excluded from the analysis, resulting in the overall elimination of 18.16%, 15.8%, 18.16% and 25.8% of the data for the reading, the fifth block (reading block) of the listening-reading and listening conditions respectively. The same logit/linear models as in Experiment 1 were fit for the examination of within-modal and cross-modal priming [3, 4].

3.4.1. Within-modal priming

Comprehension question response accuracy in reading showed a main effect of structure (β = 1.93, SE= 0.61, z = 3.13, p < .01). Question following high-attachment structure were answered more accurately than following the low-attachment structure (p< .01). There was also a main effect of block order (β = 0.30, SE= 0.13, z = 2.21, p < .001), as questions in the fifth block were responded more accurately than in the fifth block (p< .05). Furthermore, there was a structure x block order interaction (β = -0.38, SE= 0.17, z = -2.20, p < .05) as low attachment sentences in the fifth block were answered more accurately than in the first (p< .01) and second block (p<.05). There were no main effects or interaction in listening.

Error rates data for reading showed no interaction between structure and block order (β = -0.34, SE= 0.30, z = -1.15, p = .2). Similarly, in listening, there was no interaction between structure and block order (β = -0.36, SE= 0.25, z = -1.4, p = .1). Participants responded with equal accuracy to both structures throughout the whole lists in reading and listening. Given that error data of both the reading and listening list showed no priming effect, it is not possible to use it as a measure in an analysis that uses within-modal list as a control for the occurrence of cross-modal priming. Hence, error rates analysis of cross-modal priming from listening to reading and from reading to listening could not be conducted.

For the within-modal conditions, model estimates for reaction time data of the reading condition (Table 3) showed main effect of structure (β = 346.3, SE= 52.12, t = 6.6, p < .001). A significant interaction between block order and structure (β = -71.8, SE= 15.32, t = -4.6, p< .001) was also present, supporting the occurrence of cumulative priming within the reading modality for second language (L2) speaker participants. Post-hoc comparisons revealed that LA sentences in the first block elicited slower response times than sentences occurring in the second and third blocks (ps < .01) as well as fourth and fifth blocks (ps < .001). listening data revealed a main effect of structure (β = 210.8, SE= 85.8, t = 2.4, p<.01) with LA structure eliciting longer reaction times than HA structure. Unlike reading, RT data for listening showed no interaction (β = -20.6, SE= 24.3, t = -0.8, p =.3). Items throughout the within-modal listening list were processed at equal speed, suggesting the absence of cumulative priming in listening.

3.4.2. Cross-modal priming

Cross-modal priming from reading to listening cannot be conducted because of the absence of the control condition (i.e., within-modal priming in listening). To examine cross-modal priming from listening to reading, reaction times were regressed onto the main effects and interaction of sentence structure (High-attachment vs. Low-attachment) and block position (5^{th} block of cross-modal list vs. 5^{th} block of within-modal list). Comparing between the fifth block (i.e., reading block) of the listening-reading list and the fifth block of the reading list revealed no interaction (β = -88.2, SE= 64.1, t = -1.3, p =.1). Additionally, a second model was fit whereby reaction times were regressed onto the main effects and interactions of sentence structure (HA vs. LA) and block position (5^{th} block of cross-modal list vs. 1^{st} block of within-modal list). Results revealed no interaction (β = 129.1, *SE*= 72.9, t = 1.7, p=.07), hence items in the fifth block of the listening-reading list were processed at equal speed as items in the first block of the reading list. This indicates the occurrence of a weak cross-modal syntactic priming from listening-to-reading among L2 speakers (see Figure 3).

To make sure that the tested groups are comparable with regard to general proficiency, self-reported general proficiency was compared between the group pairs. Independent samples t test showed no differences in self-rated general language proficiency across all group pairs (All *p*s > .05).

Similar to Experiment 1, reaction times and error rates responses to filler items were compared across conditions to ensure that the tested groups are comparable with regard to lexical decision. Word filler items data showed no differences between the last blocks of the within-modal vs. cross-modal lists in reading reaction time (β = 24.26, *SE*= 59.35, t = 0.40) and reading error rates (β = -0.50, *SE*= 0.82, z = -0.60). Non-word filler items similarly showed no differences in reading reaction time (β = -9.06, *SE*= 55.74, t = -0.16) and reading error rates (β = -0.28, *SE*= 0.37, z = -0.75). The comparison between first block of the within-modal condition vs. last block of the cross-modal condition showed no between-group differences in word items reading reaction time (β = -100.54, *SE*= 63.59, t = -1.58), word item reading error rates (β = -0.88, *SE*= 0.96, z = -0.91), non-word items reaction time (β = -86.53, *SE*= 49.73, t = -1.74) and non-word items error rates (β = -0.28, *SE*= 0.38, z = -0.75).

4. Discussion

Current results demonstrate modality independence of syntactic priming in L1, supporting an account of shared syntactic representations between listening and reading comprehension.

Previous research employing artificial grammar paradigm showed that the ability to extract regularities from a grammatical sequence is dependent on the modality of exposure (Conway & Cristiansen, 2006; Li, Zhao, Shi, Lu and Conway, 2018). Learning a grammatical structure in one modality cannot therefore be transferred to a different modality. However, current results contrast this view. the occurrence of cross-modal cumulative syntactic priming indicates that the underlying statistical learning mechanism can transfer across modalities. Subsequently, the syntactic priming effect produced in each modality can transfer to the other causing facilitation in target processing. However, L2 speakers were found to perform differently from L1 group in the listening modality. Although cumulative priming occurred in L2 reading, no priming was observed in listening.

The discrepancy between current results and the previous evidence provided by the artificial grammar paradigm can be accounted for by distinguishing between the episodic fragmented repetition involved in artificial grammar and the transitional probability mechanism underlying language processing (Tunney & Altmann, 2001). In language, statistical learning is probabilistic, meaning that there is a probability associated with the likelihood of occurrence for each syntactic attachment. Given the repeated exposure in the current study, the likelihood that a given prepositional phrase be attached to the preceding noun rather than the verb (i.e., low-attachment) increased and was therefore attributed a higher probability whereas the high - attachment structure acquired a lower probability. In artificial grammar, what transfers is the repetitive sequential structure, whereas in priming, it is the probability associated with each syntactic attachment that transfers cross-modally. Our study, to the best of our knowledge, is the first to examine the question of modal transfer using a paradigm that differs from the artificial grammar paradigm (i.e., cumulative priming).

The absence of priming in L2 listening can be attributed to the temporal constraints associated with listening both in the current study as well as in real life. While reading is a self-paced process, listening depends on the speed of the incoming speech stream that is out of the listener's control. In the present study, despite the reading task was not self-paced for methodological reasons, sentence context in the reading modality had appeared for three seconds on the screen before the critical word was presented for 1000 ms, which allowed the visual input a prolonged presentation time in the reading condition. Conversely, the whole sentence flew at the natural speed in the listening condition. This might have hindered the occurrence of priming in listening for two reasons. First, building a syntactic structure is one step that follows on from other non-syntactic processes that are essential for efficiency. Among these processes is lexical access (Hopp, 2016). While L1 speakers can rapidly accomplish this process, research indicates that L2 speakers' lexical bottom-up processing occurs less efficiently (Roberts, 2013). In the present study, the lexical decision task contains a non-word option that delays lexical retrieval of the final critical word. Temporal constraints in listening might have not allowed L2 participants, whose mental resources are already overly consumed in the L2 lexical retrieval process, the sufficient time required for the sentence integration process that is necessary for syntactic adaptation (i.e., cumulative priming). This is supported by previous evidence that showed L2 difficulties in integrating multiple sources of information when performing time - constrained online tasks (Rah & Adone, 2008). Second, the interpretation of the low attachment ambiguity in the current study requires identifying the verb argument structure, assigning a correct thematic role to the final prepositional phrase and accordingly, ascertaining the prepositional phrase attachment. Temporal constraints imposed in listening might have prevented L2 speakers from effectively performing these parallel processes, forcing them to resort to a shallow processing strategy (Clahsen & Felser, 2006) which subsequently hinders the occurrence of the syntactic priming effect. According to the shallow structure hypothesis (Clahsen & Felser, 2006), L2 speakers rely solely on lexical-semantic representation to interpret syntactic ambiguities instead of performing structurally detailed syntactic representation. The occurrence of shared syntactic representation in reading, and not in listening in the present study suggests that L2 speakers don't engage in shallow processing all the time. Instead, factors affecting speed of processing such as task demands, and modality of presentation contribute to the occurrence of shallow processing. This goes in line with previous evidence suggesting that insufficient processing speed could result in processing difficulties in L2 (Ellis, 2005; Lopez Prego & Gabrielle, 2014).

Current results indicate that cross-modal priming is of an equal magnitude to within-modal priming in L1. This was confirmed by the additional comparison conducted between the fifth block of the cross-modal list and the first block of the within-modal list. The difference in processing between these two blocks indicated that a priming effect was accumulated throughout the cross-modal list leading sentences in the last block to be more easily processed than in the first block of the within-modal list. Accordingly, the absence of a difference between these two blocks in L2 listening to reading cross-modal analysis indicated a weak cross-modal priming effect. This result was predictable given the fact that no priming was produced in L2 listening. This evidence supports the current suggestion that the differences between L1 and L2 speakers didn't result from L2 participants inability to produce a cumulative priming effect but is rather linked to L2 less efficiency in listening.

A relevant question here is whether it is the modality of the prime trials or the target trials that hindered the priming effect in listening? Current L2 results interestingly showed the occurrence of priming, albeit a weak effect, from listening to reading, but not from listening to listening. As such, heard primes can yield a facilitation effect, indicating that it is the modality of the target trials that hinder the priming effect. Although the facilitating priming effect can build up throughout the listening prime trials, it won't show up in the target trials unless the temporal constraints and task demands are eased for L2 speakers.

Syntactic priming across the two production modalities (i.e., speaking and writing) has been demonstrated in previous research (Cleland & Pickering, 2006). Additionally, the present findings provide evidence for priming across the two comprehension modalities (i.e., listening and reading). These findings form a good foundation for a next step in which priming is examined from comprehension to production and vice versa across the four underlying modalities, (i.e., from listening to speaking and vice versa, from listening to writing and vice versa, from writing to reading and vice versa and from speaking to reading and vice versa). The resulting findings would give insight into shared mechanisms and representations underlying comprehension and production. Multiple contradictory views are related to the connection between comprehension and production. First, there are views that support the existence of separate modular instantiation of the processes underlying production and comprehension (Chomsky, 1965). Second, Dell and Chang (2014) proposed the P-Chan model in which production is linked to comprehension through predictive processing. Production of a linguistic content provides top-down effects that are needed for the comprehension process of generating predictions about the upcoming input. Therefore, the model predicts the occurrence of facilitation in processing from production to comprehension, but not vice versa. Finally, the interactive alignment model by Pickering and Garrod (2004) relies on the alignment of produced and comprehended utterances within dialogues to account for the connection between comprehension and production. A future examination of bidirectional priming effects across comprehension and production would reconcile between the existing contradictory views. A recent study has indeed supported bi-directional effects across production and comprehension through trial-to-trial priming (Litcofsky & van Hell, 2019); however, it is still to be seen whether these effects persist across the four underlying sensory modalities (reading, listening, speaking, and writing), and whether these bidirectional effects can be found in cumulative priming rather than in trial-to-trial priming effect which tends to be a short-lasting effect (Pickering &Branigan, 1999).

5. Conclusion

Current results supported the abstractness of syntactic priming by showing bidirectional syntactic priming across the two comprehension modalities in L1. This study is the first to reveal that although L2 speakers show priming in reading, no priming effect was found in listening. In addition, weak effect was demonstrated in the listening-reading condition. Given the observed priming in reading and the absence of priming in listening, we can attribute the effect to a difficulty in listening among L2 speakers, rather than to an inability to produce abstract priming. We propose that L2 speakers may not be less susceptible to syntactic adaptation, but may need more time when listening to efficiently comprehend and process sentences. The current results indicate the ability of both L1 and L2 speakers to adapt to the syntactic probabilities of the encountered linguistic environment.

Footnotes

1- In reading, the error rates model included random intercepts for subject and item. The reaction time model included random intercepts for subject and item, by-subject random slopes for structure, trial order and stimulus order in addition to by-item random slopes for trial order and stimulus order. In listening, the error rates model included random intercepts for subject and item. The reaction time model included by-subject random slopes for structure, trial order and stimulus order, and by-item random slope for structure.

2- Model comparing the fifth blocks of listening and reading-listening lists included random intercepts for subject and item and by-item random slope for group. Model comparing first block of the listening list to fifth block of the reading-listening list included random intercepts for subject and item in addition to by-item random slope for group. Model comparing fifth blocks of the reading and listening-reading lists included random intercepts for subject and item, by-subject random slope for structure and by-item random slope for structure. Model comparing first block of the reading list to fifth block of the listening-reading list included random intercepts for subject and item.

3- In reading, the error rates model included random intercepts for subject and item. The reaction time model included random intercepts for subject and item, by-subject random slope for stimulus order and by-item random slopes for structure and stimulus order. In listening, the error rates model included random intercepts for subject and item. The reaction time model included random intercepts for subject and item, by-subject random slopes for trial order and stimulus order, and by-item random slope for structure.

4- Model comparing fifth blocks of the listening and reading-listening lists included random intercepts for subject and item. Model comparing first block of the listening list to fifth block of the reading-listening included random intercepts for subject and item. Model comparing fifth blocks of the reading and listening-reading lists included random intercepts for subject and item. Model comparing first block of the reading list to fifth block of the listening-reading list included random intercepts for subject and item.

Data Availability Statement

The datasets supporting this article have been uploaded as part of the electronic supplementary material.

Declaration of Conflicting Interests

The authors declare that there is no conflict of interest.

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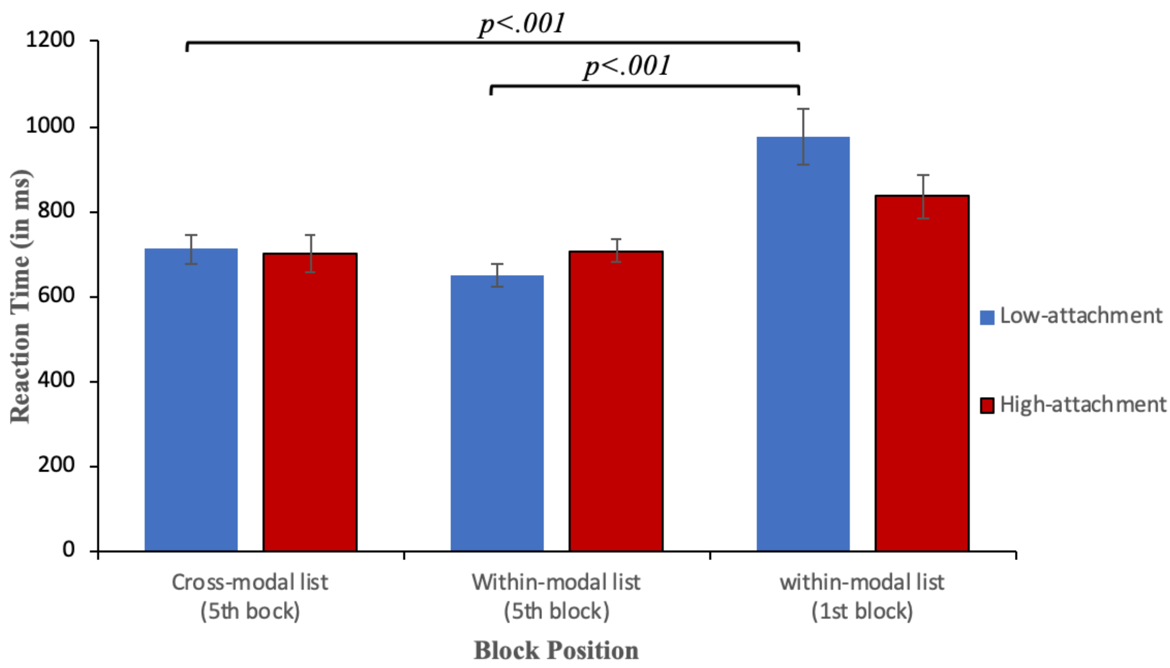
Tables

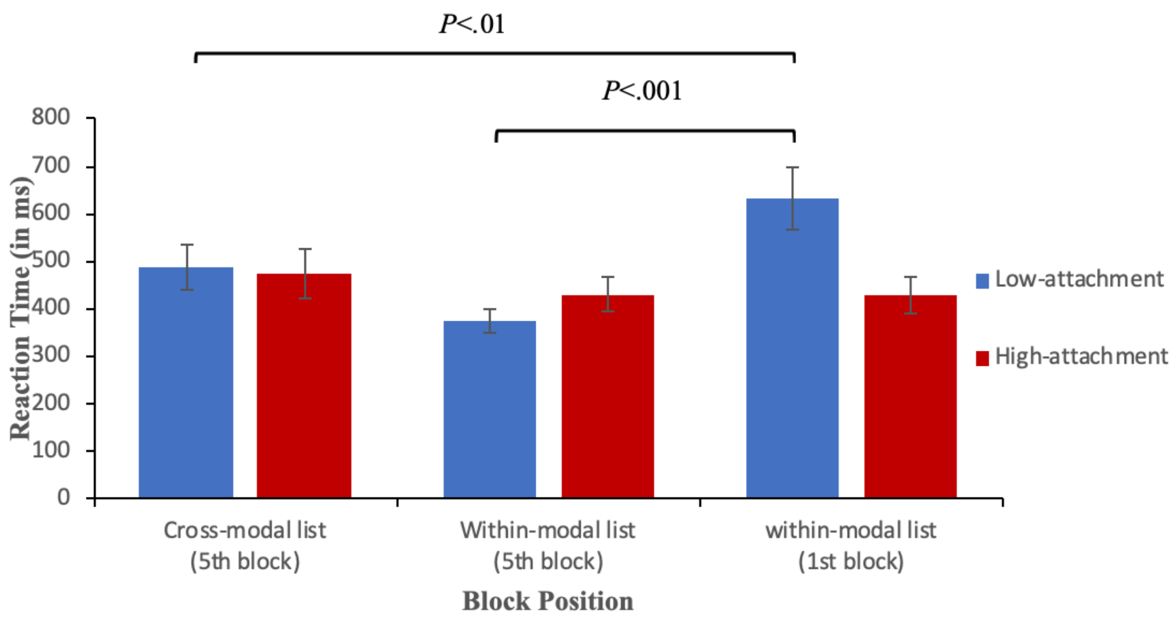
	Listening			Reading		
Coefficient	**Estimate**	**S.E.**	**t-value**	**Estimate**	**S.E.**	**t-value**
Intercept	393.39	123.08	3.19	1066.55	109.35	9.75
Structure	208.59	50.71	4.11	216.74	43.17	5.02
Block order	1.41	20.64	0.06	13.06	21.36	0.61
Stimulus order	30.06	106.68	0.28	-201.70	93.14	-2.16
Structure X Block order	-60.52	13.68	-4.42	-63.63	12.79	-4.97

Skill	Mean Proficiency (7 points)
Listening	5.46 (0.81)
Speaking	6.09 (0.83)
Reading	6.15 (0.97)
Writing	5.65 (0.79)
General proficiency	5.45 (0.53)

	Listening			Reading		
Coefficient	**Estimate**	**S.E.**	**t-value**	**Estimate**	**S.E.**	**t-value**
Intercept	540.37	237.69	2.27	1166.26	154.79	7.53
Structure	210.87	85.80	2.45	346.38	52.12	6.64
Block order	-60.90	50.45	-1.2	-10.01	22.25	-0.45
Stimulus order	297.35	244.75	1.21	-105.39	117.81	-0.89
Structure X Block order	-20.66	24.30	-0.85	-71.86	15.32	-4.68

Figures


p<.001
p<.001
1200
1000
800
600
400
200
0
Reaction Time (in ms)
Low-attachment
High-attachment
Cross-modal list
(5th bock)
Within-modal list
(5th block)
within-modal list
(1st block)
Block Position


P<.01
P<.001
800
700
600
500
400
300
200
100
0
Reaction Time (in ms)
Low-attachment
High-attachment
Cross-modal list
(5th block)
Within-modal list
(5th block)
within-modal list
(1st block)
Block Position

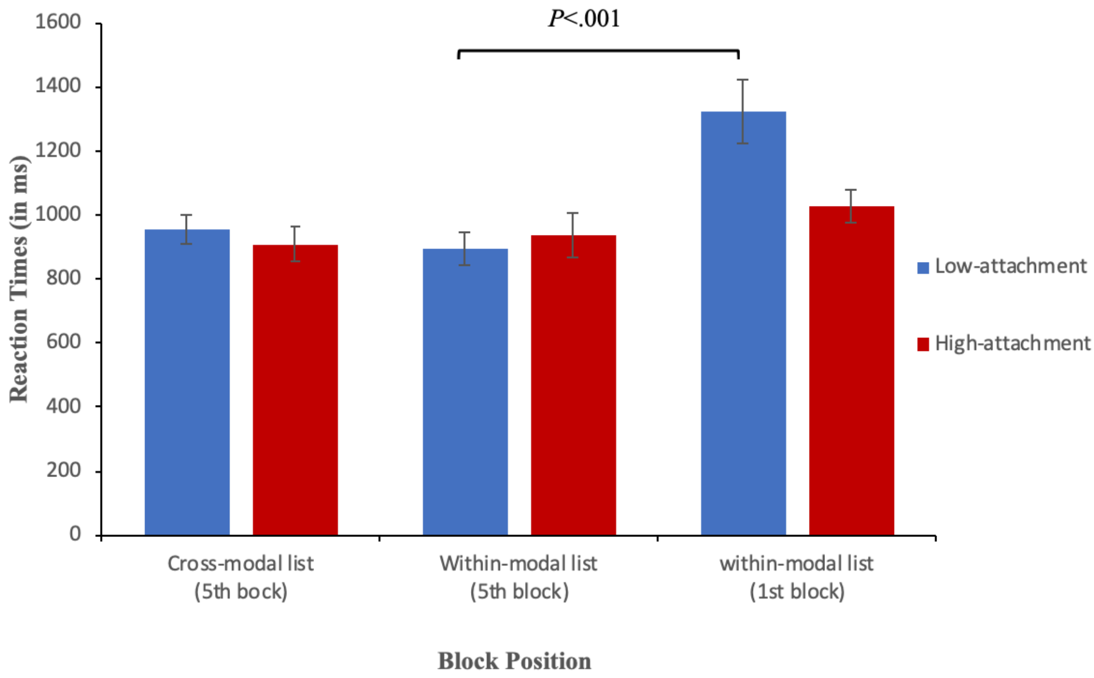

P<.001
1600
1400
1200
1000
800
600
400
200
0
Reaction Times (in ms)
Low-attachment
High-attachment
Cross-modal list
(5th bock)
Within-modal list
(5th block)
within-modal list
(1st block)
Block Position

Table and figure captions

Table 1. *Mixed effects model estimates for reaction times in within-modal listening and reading, first language speakers.*

Table 2. *Mean self-reported ratings (7-point Likert scale) of proficiency in English as a second language for Experiment 4 (Standard deviations are between parentheses).*

Table 3. *Mixed effects model estimates for response times in within-modal listening and reading, second language speakers*.

Figure 1. Reaction times (in ms) in reading split by structure and block position for first language speakers. Low-attachment target words are shown as blue bars and high-attachment target words as red bars. The error bars indicate SEM.

Figure 2. Response times (in ms) in listening split by structure and block position for first language speakers. Low-attachment target words are shown as blue bars and high-attachment target words as red bars. The error bars indicate SEM.

Figure 3. Response times (in ms) in reading split by structure and block position for second language speakers. Low-attachment target words are shown as blue bars and high-attachment target words as red bars. The error bars indicate SEM.