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Influence of syntactic complexity on L2 prediction

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Abstract

This study investigated the influence of syntactic complexity on prediction in second language (L2) processing. In a visual world eye-tracking experiment, we compared L2 listeners' prediction while processing simple (e.g., *The dancer will open/ get the present*) vs. complex sentences (e.g., *I know the friend of the dancer that will open/ get the present*). Prediction was measured by comparing fixations to the targets (e.g., present) between semantically biasing (e.g., *open*) vs. neutral verb (e.g., *get*) conditions. Results showed that L2 listeners predicted while processing complex as well as simple sentences, but the prediction effect during complex sentence processing emerged somewhat later. These findings suggest that L2 prediction is influenced by syntactic complexity which can increase cognitive load during sentence processing.

Introduction

Research suggests that first language (L1) speakers are likely to predict upcoming linguistic information during comprehension (see Kuperberg & Jaeger, 2016, for a recent review). Findings of linguistic prediction has advanced our understanding of and provided important theoretical implications for language processing and learning (e.g., Chang et al., 2006; Pickering & Garrod, 2013). Specifically, proactive anticipation of upcoming linguistic information suggests that top-down processing is much more engaged in comprehension than it was traditionally considered (Marslen-Wilson, 1973). In addition, as prediction facilitates comprehension, predictive processing could partly account for L1 speakers' rapid comprehension with great ease (Altmann & Kamide, 1999; Altmann & Mirković, 2009; Federmeier, 2007; Kamide et al., 2003). Finally, linguistic prediction has provided supporting evidence for learning accounts which propose that prediction mechanisms underlie implicit learning (e.g., the error-based learning account; Chang et al., 2012). Under these learning accounts, learning is claimed to occur in the process of reducing prediction error and thus predictive processing is considered vital for learning (for discussion, see Hopp, this volume).

Given these theoretical implications, it is no surprise that a great deal of attention has been paid to prediction in second language (L2) learners as well. L2 speakers' comprehension has typically been shown to be slower and more difficult than L1 speakers' comprehension, and this could possibly be related to L2 speakers' lack of predictive abilities (Brouwer et al., 2017). Accordingly, research on L2 prediction has primarily focused on L2 speakers' predictive ability, namely whether they are able to predict and if so, whether they can predict to the same extent as L1 speakers (Dijkgraaf et al., 2017; Grüter et al., 2012; Grüter et al., 2014; Martin et al., 2013). Such studies manipulated different types of predictive cues and reported findings that L2 speakers are able to predict (Chambers & Cooke, 2009; Dijkgraaf et al., 2017; Koehne & Crocker, 2015). However, L2 speakers' engagement in prediction seems to vary depending on the types of predictive cues, interacting with multiple factors that influence L2 processing in general (e.g., age of acquisition, L2 proficiency, and cross-linguistic differences between L1 and L2). These interactions remain rather unclear, as do the factors modulating L2 speakers' predictive processing. Exploring the interactions or the mediating factors will provide a better picture of linguistic prediction and ultimately help us better understand predictive mechanisms as well as develop theoretical accounts of linguistic prediction. The current study therefore aims to contribute to this strand of research by investigating whether L2 prediction is influenced by syntactic complexity.

Prediction in comprehension

There has been a surge of research on linguistic prediction during the last two decades, and such studies yielded the consensus that L1 speakers – children as well as adult speakers - make predictions about upcoming linguistic input during comprehension (Altmann & Kamide, 1999; Kuperberg & Jaeger, 2016). Prediction in this paper is defined as pre-activation of upcoming linguistic input (Huettig & Guerra, 2019; Pickering & Gambi, 2018). Suppose that a comprehender processes a sentence like *On his birthday, the boy cut the cake*. If comprehenders predict 'cake', some linguistic information regarding *cake* (e.g., conceptual feature +EATABLE, some phonological feature /keɪk/, and grammatical gender information of *cake* if the language marks gender) is pre-activated upon reading or listening to *cut the* (i.e., before they read or listen to the word *cake*).

Pre-activation of such linguistic information has predominantly been measured using electrophysiological responses or eye movements. Using the phonological regularity in English (e.g., *a* + consonant-initial words and *an* + vowel-initial words), DeLong et al. (2005) designed an eletroencephalography (EEG) experiment to measure pre-activation of specific articles and nouns. Native English participants read sentences of varying constraint (e.g., *The day was breezy so the boy went outside to fly...*) that included target articles and nouns with ranges of cloze probability (e.g., *a kite* is highly likely whereas *an airplane* is less likely in the given example sentence). When participants were expecting *a kite* but *an airplane* was presented, the violation of the phonological regularity would elicit a change in the amplitude of the ERPs for the articles. As expected, the amplitude of the N400 elicited by the articles varied depending on article expectancy. The N400 was larger when the cloze probability of the article and noun was smaller. Since the articles were grammatically and semantically congruent within the contexts, the negative correlation between the N400 amplitude at the article and the article cloze probability was interpreted as suggesting that L1 readers make probabilistic predictions about upcoming nouns and pre-activate some phonological information of the words. That is, as they anticipate the phonological form of a noun (e.g., a consonant-initial word, *kite*) and expect one article (e.g. *a*) relative to the other (e.g., *an*), they would experience integration difficulty when the less-expected article was presented (see Nieuwland et al., 2018, for different findings).

Stronger evidence for prediction comes from the visual world eye-tracking studies which measure listeners' anticipatory looks to the upcoming referents in a visual display. For example, Altmann and Kamide (1999) recorded eye movements from L1 English speakers while they were listening to sentences containing semantically restrictive verbs (e.g., *"The boy will eat the cake"*) or neutral verbs (e.g., *"The boy will move the cake"*). When presented with a scene depicting a cake and inedible objects, these English speakers' fixations on the cake increased as soon as the constraining verb was heard. Crucially, participants showed more fixations on the cake than the other objects even before they heard the direct object *cake*. These anticipatory eye movements suggest that L1 listeners predict plausible direct objects using the selectional restrictions of verbs. To date, visual world eye tracking studies have shown that L1 speakers use various types of cues to predict upcoming information (e.g., semantic cues: Altmann & Kamide, 1999; Kamide et al., 2003; syntactic cues: Arai & Keller, 2013; discourse cues: Otten et al., 2007; prosodic cues: Ito & Speer, 2008; Nakamura et al., 2012; Perdomo & Kaan, 2019).

Prediction in L2 comprehension

Prediction is not only resource-expensive processing, but it also entails the risk of failure. Building up expectations during computations of ongoing information already requires more cognitive resources than simply integrating information which unfolds in a rapid fashion. It demands further cost if the predictions do not match the actual linguistic input and thus need to be rapidly revised while the processor also needs to keep up with the ongoing information. Considering the high expense, generating predictions can be challenging or risky for L2 speakers and may not be possible for those who are already overburdened by online integrative processing during comprehension. Therefore, L2 speakers have been claimed to have Reduced Ability to Generate Expectations (the RAGE Hypothesis; Grüter et al., 2014). Studies on L2 prediction revealed that the influence of RAGE on L2 processing differs depending on linguistic cues, interacting with various factors that influence L2 processing in general.

When semantic cues are available in the context, L2 speakers are likely to use them predictively, often to a similar extent as L1 speakers. Chambers and Cooke (2009) replicated Altmann and Kamide's (1999) semantic prediction effect with L2 speakers. When presented with French sentences like *Marie va nourrir la poule* ('Marie will feed the chicken') or *Marie va décrire la poule* ('Marie will describe the chicken'), late L2 learners of French with high proficiency showed more anticipatory looks to the target picture of *poule* ('chicken') upon hearing the verb *nourrir* ('feed') compared to hearing the verb *décrire* ('describe'). Such semantic cues could be readily used for prediction by L2 speakers even at the beginning level (Koehne & Crocker, 2015). Unbalanced bilinguals also showed semantic prediction in both L1 and L2, and their semantic prediction in L1 did not differ from monolinguals' prediction (Dijkgraaf et al., 2017). Importantly, semantic prediction in L2 has been shown to be affected by the spread of semantic activation (Chambers & Cooke, 2009; Dijkgraaf et al., 2019). In a study using a visual world paradigm, Dijkgraaf et al. (2019) tested whether bilinguals make semantic predictions to the same extent in their L1 and L2. When presented with a display containing a picture of either a target or a semantic competitor and three unrelated objects, bilinguals showed more anticipatory fixations on the target and the semantic competitor than on the other objects in both L1 and L2. They also showed more anticipatory fixations to semantically related competitors than the other objects, and this effect appeared stronger and earlier in their L1 than in L2. These findings indicate that semantic predictions in L2 are made in a similar fashion as those in L1, but the extent of semantic prediction seems to be influenced by the spread of semantic activation. L2 speakers' inevitable experience of lexical competition through cross-lingual word coactivation and their lower language experience in L2 could result in weaker semantic representations, which in turn may be attributable to weaker and slower semantic activation during L2 semantic prediction.

As for (morpho)syntactic cues, prior studies revealed mixed findings with much more variance. Some studies found that L2 speakers show difficulties in using (morpho)syntactic information for prediction (e.g., Grüter et al., 2012; Lew-Williams & Fernald, 2010; Martin et al., 2013; Mitsugi & MacWhinney, 2016) whereas others demonstrated that L2 speakers could use this type of information predictively (e.g., Dussias et al., 2013; Foucart et al., 2014; Schlenter & Felser, this volume). The picture emerging from recent studies is that syntactic prediction in L2 interacts with factors such as L2 speakers' proficiency and their L1 backgrounds. For instance, intermediate L2 Japanese learners who had grammatical knowledge about Japanese case markers could not utilize the case marking information to predict an upcoming word (Mitsugi & MacWhinney, 2016). Similarly, moderately proficient English learners of Spanish could not use grammatical gender information for prediction despite their relevant grammatical knowledge. In contrast, highly proficient L2 speakers could use grammatical gender information for prediction in a native-like way (Dussias et al., 2013; Schlenter & Felser, this volume). Furthermore, L1 backgrounds seem to have a significant influence on syntactic prediction in L2. In contexts where the L1 shared similar syntactic properties with the L2, L2 speakers could use syntactic information to make predictions. van Bergen and Flecken (2017) tested three groups of Dutch learners with different L1 backgrounds (English, French and German), and only those with German L1 background, whose L1 similarly encodes object position, could make use of Dutch placement verbs to predict object position. This pattern was observed regardless of age of acquisition. Both early and late L2 learners could make syntactic predictions in a similar manner to L1 speakers when the same syntactic feature (e.g., gender agreement rule) exists in L1 and L2 (Foucart et al., 2014; see also Foucart, this volume).

Variation in prediction and mediating factors

As introduced above, L2 speakers show large variability in prediction. However, the case is not limited to L2 speakers. The current literature reveals variation in prediction within and across populations (Federmeier, 2007; Federmeier et al., 2002; Huettig & Guerra, 2019). Considering that prediction is basically part of language processing, which is constrained by timing, whatever influences language processing in general can be considered to give rise to variation in prediction within and across speakers. Exploring this variation will help us further understand how prediction mechanisms work.

Studies showing when predictions fail provided as much information about predictive mechanisms as ones showing when predictions succeed. For instance, Chow et al. (2018) investigated the impact of argument role information on verb predictions using the *ba* construction in Mandarin Chinese. The particle *ba* is always positioned between the subject and the direct object (i.e., subject + *ba* + object +

verb). Therefore, syntactic roles of preverbal arguments are easily noticeable in this construction, and the likelihood of an upcoming verb is changed by the arguments' structural roles. That is, the verb, *arrest* is more likely to appear in a sentence like *Jingcha ba xiaotou* ... ('cop BA thief …') than in a sentence like *Xiaotou ba jingcha* ... ('thief BA cop …'). In an ERP study using this *ba* construction, Chow et al. manipulated argument role information (canonical vs role-reversed sentences) and predictability (high vs. low predictability) in Experiment 1, and the linear distance between the pre-verbal arguments and the verb (e.g., '*cop ba thief (yesterday after noon) arrest'*) in Experiment 2. Results of this study showed that L1 comprehenders failed to predict verbs using argument role information (i.e., no N400 effect by argument role reversals even in the high predictability condition), but their verb predictions were sensitive to this information when the context was highly predictable and more time was available (i.e., an N400 effect by argument role reversals in the the long-distance condition with high predictability). The delayed impact of argument role information on verb prediction indicates that verb predictions evolve over time. Chow et al. interpreted these findings as suggesting that prediction involves computations requiring different amounts of time. In addition, Huettig and Guerra (2019) observed that L1 prediction is constrained by experimental conditions such as speech rate, preview time of visual context, and participant instructions. While listening to normal speech, L1 comprehenders showed prediction effects only when they were given extensive preview time (4 sec), but not when they had short preview time (1 sec). Also, they showed only a small prediction effect under the condition with a normal speech rate and a short preview even though they were explicitly instructed to predict. These results provided evidence against the notion that human brains are essentially prediction machines (Clark, 2013).

Furthermore, variation in prediction prompted research exploring potential factors that influence predictive processing and helped us understand which factors play an important role in prediction. According to Huettig and Janse (2016), L1 adult speakers' syntactic prediction is modulated by their working memory abilities and processing speed. The better working memory and the faster processing speed, the more likely that L1 comprehenders predict (but see Otten & Van Berkum, 2009, for a failure of finding effects of working memory span on prediction). Regarding inconsistent prediction effects in L2, Mitsugi and MacWhinney (2016) suggested that this may be due primarily to limited cognitive resources in L2 speakers. During sentence comprehension, speakers need to retrieve relevant information from memory and integrate this information as the sentence unfolds. They also need to integrate non-linguistic information from the language environment with the linguistic information that they retrieved from memory. In this process, if L2 speakers use up cognitive resources for complex online computations, few resources may be left for prediction (see Ito, this volume). Given that greater cognitive resources are required for L2 comprehension than L1 comprehension (Segalowitz & Hulstijn, 2005), L2 speakers may have difficulties in accessing necessary knowledge for prediction (e.g., grammatical knowledge) particularly when they are given complex cues (e.g., combinations of semantic and syntactic information).

This view is in line with the RAGE hypothesis under which the limitation of L2 prediction is because of cognitive burden that L2 speakers experience during online computation of linguistic input. This issue was more directly addressed in some recent studies. With the hypothesis that increased cognitive load would interfere with prediction, Ito et al. (2018) investigated the relationship between cognitive load and predictive eye movements in both L1 and L2 speakers. In visual world eye-tracking experiments, half of the participants in each speaker group listened to sentences with a simple SVO structure (similar to those used in Altmann and Kamide, 1999) and clicked a mentioned object on the visual displays (i.e., listen-and-click task only). The other half performed an additional working memory task. Compatible with previous findings, both groups of participants who did the listen-and-click task only showed more anticipatory fixations on the plausible objects (e.g., scarf) when listening to semantically restrictive verbs (e.g., *fold*) than when listening to semantically neutral verbs (e.g., *find*). However, this semantic prediction effect was delayed for those who performed the concurrent working memory task in both L1 and L2 speaker groups. These findings were taken to support the view that an additional working memory task can impose a cognitive load even during simple sentence processing and consequently delay the prediction effect.

However, the study by Ito et al. lacked ecological validity in that the cognitive load externally imposed by the memory task is far from the cognitive challenges that speakers usually experience during sentence processing. The effects of cognitive load on prediction can be investigated in a more natural setting by manipulating syntactic complexity. L2 speakers have shown difficulties when they process complex sentences, and their processing is modulated by cognitive capacities (Dussias & Piñar, 2010; Zhou et al., 2017). These findings imply that syntactic complexity is one of the factors which can increase cognitive load during sentence processing. In this regard, Chun and Kaan (2019) investigated whether L2 speakers are able to make predictions even while processing complex sentences. Thus far, semantic prediction during simple sentence processing has been well-attested, and therefore their study solely focused on the comparison of prediction during complex sentence processing between L1 and L2 speakers. In a visual world eye-tracking experiment, participants listened to relative clause (RC) sentences with complex noun phrases (e.g., *I know the friend of the dancer that will open/ get the present*) containing either semantically biasing or neutral verbs. As processing complex sentences would increase cognitive load and more cognitive resources are required for L2 processing than L1 processing, L2 speakers were expected to feel overburdened by online computation itself and fail to make predictions during complex sentence processing. Contrary to this expectation, L2 speakers showed native-like prediction, directing their eyes to the predictable target object (e.g., present) based on the semantic information of the verbs while processing complex sentences.

Despite the novel finding of L2 prediction effects during complex sentence processing, Chun and Kaan’s (2019) study had some limitations. They did not include comprehension questions for the sake of examining prediction during natural sentence processing. As participants’ comprehension was not probed, the authors could not exclude the possibility that L2 participants did not fully parse the structures (i.e., shallow processing). If this was the case, those who had not fully parsed the structures might have not used up resources for online computation, which could have led them to use resources for prediction. In other words, L2 participants could just focus on the verb information (e.g., *open*) and anticipate the plausible direct objects (e.g., *present*), without attaching the RC to any of the noun phrases (NPs). They then might not have experienced much cognitive load and used resources for prediction even during complex sentence processing. In addition, Chun and Kaan compared prediction effects between L1 and L2 speakers only during complex sentence processing, and their results did not inform us of the extent to which syntactic complexity can influence L2 prediction. The present study was therefore designed to extend Chun and Kaan's (2019) study by ruling out the possibility of incomplete parsing (using comprehension questions) and including a simple sentence condition.

The current study

In this study, we conducted a visual world eye-tracking experiment to investigate the influence of syntactic complexity on L2 prediction. We included comprehension questions to encourage L2 speakers' full parsing. We also compared L2 prediction during simple vs. complex sentence processing to understand the extent to which syntactic complexity influences L2 prediction.

To replicate L2 prediction during complex sentence processing, we used the same sentences as those in Chun and Kaan (2019) for the complex sentence condition. We manipulated semantic associations between the critical elements (e.g., between the agent and the verb, and between the verb and the theme) to provide semantic cues. We created the materials for the simple sentence condition (e.g., *The dancer will open the present*) by extracting critical elements from the complex sentences (e.g., *I know the friend of the dancer that will open the present*). This was to keep the semantic cues consistent between the two sentence conditions. In this way, the materials in both sentence conditions could only differ in terms of syntactic complexity while keeping all the key lexical items identical. However, the same lexical items between the two sentence conditions could yield repetition effects, and thus we employed a between-subject design. Based on the previous findings that cognitive load delays prediction effects (Ito et al., 2018), we expected L2 prediction to be delayed during complex sentence processing if syntactic complexity increases cognitive load for online computations and in turn influences prediction.

Method

Participants

Fifty Chinese learners of English were recruited from a university in Hong Kong. They participated in this study for monetary compensation ($80 HKD per hour). Half participants were exposed to the simple sentences and the other half to the complex sentences. None of these participants had hearing problems or learning disorders. Before the main experiment, all participants completed informed consent forms approved by the Institutional Review Board of the university. A battery of tests was used to examine participants' working memory capacity and linguistic proficiency: a reading span task (Kane et al., 2004), the Shipley vocabulary test (Shipley, 1940), and the grammar and cloze section of the MELICET(Michigan English Language Institute College English Test; University of Michigan, 2001). We also collected self-reported scores of IELTS (International English Language Testing System). Participant information is provided in Table 1. The two groups of L2 participants did not differ in working memory capacity (the reading span task: $t(47.23)= -0.12$, $p = .91$), vocabulary size (the Shipley test; $t(47.62)=1.76$, $p = .08$) or any measures of proficiency (IELTS: $t(41.69) = -0.67$, $p = .51$; the Grammar and Cloze section of MELICET: $t(48)= 0.46$, $p = .65$).

< Table 1 around here >

Stimuli

In order to assess participants' use of semantic cues for prediction, half of the sentences in each sentence condition included semantically biasing verbs and the other half included neutral verbs. The experimental stimuli for the complex sentence condition consisted of fourteen pairs of sentences including object-modifying and subject-extracted relative clauses (e.g., *I know the friend of the dancer that will open/ get the present*). As for the experimental stimuli for the simple sentence condition, fourteen pairs were created by extracting the second noun phrase (NP2), the verb, and the object in the RCs from the complex sentences (e.g., *The dancer will open/get the present*). That is, the simple sentences contained exactly the same verbs and the objects as those in the RCs from the complex sentences, and the subjects of the simple sentences always corresponded to the NP2 of the complex sentences. In this way, the semantic information for predictive cues was controlled for between the two sentence conditions (simple vs. complex). Sixteen RC sentences with one NP (e.g., *"The chef knows the girl that will cook the chicken"*) were prepared for the fillers and used for both conditions.

The complex sentences were recorded by a female native American English speaker at the sampling rate of 44.1 kHZ. They were recorded at a rate of 3.1 words per second. The duration of the verb and the determiner was kept constant across the items (i.e., verb + *the*: 642 ms). This was to provide participants with the same amount of time to make predictive eye movements. Then, the auditory stimuli for the simple sentence condition were spliced from those for the complex sentence condition. In this way, not only the speech style and rate but the duration of the critical time window for prediction was also consistent across the items in both conditions. For the visual displays, we prepared fourteen scenes that depicted three objects (e.g., a target and two distractors) and two agents (e.g., a boy and a girl) referring to the two noun phrases in the complex sentences (see Figure 1). The item which can be an appropriate theme of the semantically biasing verb was coded as the target. The two distractors were as likely to be the themes of the semantically neutral verb as the target. For example, the target *present* in Figure 1 is the only item that can be the theme of *open* whereas the distractors *money* and *trophy* can be as likely to be the themes of *get* as the target *present.* To verify this semantic manipulation, a norming study was separately conducted with native speakers of American English ($N = 101$). Participants were asked to complete a given sentence fragment (e.g., *The boy will open/ get* _____) using any object on the visual display. In this test, participants chose the target item 96% of the time when the biasing verb was presented whereas they did so 42% of the time when the neutral verb was presented. The locations of the targets and the distractors were randomized on each trial.

< Figure 1 around here >

We prepared comprehension questions (e.g., *Who will open the present?*) to encourage participants to fully parse the experimental sentences. Since there were no correct answers for the ambiguous RCs in the complex sentence condition, participants' parsing accuracy could not be checked. However, research has shown that speakers have attachment bias when parsing ambiguous RC sentences. Thus, we prepared a quick behavioural task to identify each participant's attachment bias and compared their attachment interpretations in the behavioral task with their comprehension answers during the eye-tracking task. For this behavioral task, we prepared four sets of auditory stimuli with each set consisting of nine ambiguous RC sentences (e.g., *Michelle sees the child of the mother that is talking to the woman*) and twelve fillers (RC sentences with one NP). Participants' comprehension answers during the eye-tracking task were expected to be parallel to their RC attachment interpretations in the behavioral task on the assumption that they would use their attachment bias when processing the ambiguous RCs in the complex sentence condition.

Procedure

The behavioral task to identify participants' attachment bias was first administered using E-prime (Psychological Software Tools). The lists of ambiguous RC sentences were counterbalanced across participants and the experimental sentences in each list were pseudorandomized with the fillers intervening one or two experimental sentences. In this behavioral task, participants were instructed to listen to auditory sentences (e.g., *Michelle sees the child of the mother that is talking to the woman*) via headphones and answer questions (e.g., *Who is talking to the woman?*) by pressing a button which corresponded to the first noun phrase (NP1) or the second noun phrase (NP2).

Then, the visual world eye-tracking task was conducted on an Eyelink 1000 system with a chin rest. Before the beginning of the experiment, we completed an automatic 9-point calibration and validation routine using a standard black and white bull's eye image. Recalibration was conducted during the experiment whenever necessary. The visual displays were presented using a PC computer running EyeLink Experiment Builder software (SR Research, Mississauga, Ontario, Canada) and auditory stimuli were presented using the same computer via head phones. While listening to auditory sentences, participants' eye movements were recorded at a 500 Hz sampling rate. Before the main experiment, participants practiced with 5 trials and the practice was repeated until they understood the task.

Each trial started with a bull's eye image at the center of the screen which served as a drift correction. Participants were instructed to fixate on it and press the space bar whenever they were ready to proceed. Once the space bar was pressed, a visual display was presented for 2000ms before the onset of a sentence. After this preview, participants heard auditory sentences and clicked the last-mentioned object from the auditory stimuli. The visual display remained on the screen until they clicked. The behavioral mouse-clicking was to encourage participants to pay attention to the task and look at the visual display. Finally, participants answered comprehension questions by pressing buttons. The same questions were presented for both sentence conditions (e.g., *Who will open the present?*), but the questions were used to probe RC attachment interpretations for the complex sentence condition. The trials of the eye-tracking task were randomly presented.

Results

Behavioral task accuracy

The accuracy of the mouse-clicking responses was 99.3 % in the simple condition and 93.4 % in the complex condition. With regards to comprehension accuracy, participants in the simple sentence condition showed 96.7% accuracy. For the complex sentence condition, participants' comprehension answers were significantly correlated with their attachment interpretations in the behavioural task ($r(23) = .43$, $p = .03$). This result suggests that participants in the complex sentence condition parsed the ambiguous RC structures following their attachment bias.

Eye-tracking data analysis

The eye-tracking data were analyzed using the lme4 package (Bates et al., 2015) in R (R Core Team, 2016). First, we preprocessed the eye-tracking data using the VWPre package (Porretta et al., 2017). The fixation proportions on the target and the other objects were calculated for each 20 ms time bin relative to the onset of the target noun, and then fixation probability in every time bin was transformed into log odds, using the empirical logit function (Barr, 2008) installed in the package. Track loss or blinks were not included for fixations, and the trials with incorrect mouse-clicking responses and comprehension answers were excluded for the eye-tracking analysis.

Figure 2 plots the fixation proportions to the targets between the biasing (the solid lines) and the neutral verb conditions (the dotted lines) in the simple and complex sentence conditions. This time-course plot shows mean fixation proportions to the targets from 1000ms before to 1000ms after the onset of the target noun. The plot was time-locked to the onset of the target noun (the vertical solid line at time zero) and the vertical dashed line marks the onset of the verb in the spoken sentence. The error-bands indicate 95% bootstrapped confidence intervals of mean fixation proportions to the targets. As seen in Figure 2, L2 participants in both simple and complex sentence conditions showed more anticipatory looks to the targets in the biasing versus the neutral verb conditions before they heard the target noun.

< Figure 2 around here >

For statistical analysis of the prediction effect, we constructed a linear mixed effects model over the log-transformed fixation probabilities on targets from 442 ms before to 200 ms after the target noun onset. To meet the statistical assumption that the dependent variable has an unbounded range, we used the log-transformed fixation probabilities as the dependent variable (Barr, 2008). The analysis window was set considering a latency of 200 ms for eye movement planning (Matin et al., 1993), and the duration of the verb and the determiner (642 ms). The eye movements during this time window would capture prediction using semantic information of the verb before encountering the noun. For the fixed effects, the model included contrast coded verb type (neutral verb coded as -0.5 vs. biasing verb coded as 0.5), sentence type (simple sentence coded as -0.5

vs. complex sentence coded as 0.5), and an interaction between verb type and sentence type. For the random effects, the model included random intercepts for participants and items, and verb type as a by-participant random slope. The final model did not include a by-item random slope for verb type because the model with it did not converge (see the summarized results of the final model in table 2). In support of the fixation differences between the two verb conditions as shown in Figure 2, L2 participants' anticipatory fixations onto the targets were significantly influenced by verb type (b = 0.55, SE = 0.14, t = 3.96, p < .001). Participants showed more anticipatory fixations onto the targets as soon as they heard the biasing verb rather than the neutral verb (mean fixation proportions to targets: 0.32 for the simple sentence condition and 0.28 for the complex sentence condition).

< Table 2 around here >

However, there was neither a main effect of sentence type nor an interaction between sentence type and verb type. This may be because the time window collapsed over for the analysis was so wide that potential differences between the two sentence conditions may have been obscured. We therefore conducted a time-course analysis following previous work

(Borovsky et al., 2012; Ellis et al., 2015; Ito et al., 2018). A separate model for each sentence condition was run for every 40 ms bin from 442ms before to 500 ms after the target noun onset. The model included the fixed factor of verb type, random intercepts for participants and items, and verb type as a by-participant random slope. Since this type of time-course analysis can increase the likelihood of Type I errors, researchers have been conservative when reporting results (Baayen, Davidson, & Bates, 2008). They typically report results showing consistent reliability with the absolute t-value exceeding 2 over multiple bins (e.g., more than three to five consecutive bins). Significance of the time-course analysis is shown on the top of the graphs in Figure 2. A solid circle (•) indicates significant differences in fixations on the targets between the two verb conditions in each time bin ($|t|$s > 2). Results of this analysis showed that prediction effects consistently appeared from 82 ms before the target noun onset in the simple sentence condition, but they appeared from 78 ms post target noun onset onwards in the complex sentence condition.

Discussion

This study investigated the influence of syntactic complexity on predictive eye movements in L2 speakers. In a visual world eye-tracking experiment, half of the participants listened to simple sentences and the other half listened to complex sentences. For each sentence condition, half of the sentences contained semantically biasing verbs and the other half contained semantically neutral verbs. The results showed that L2 listeners made more anticipatory looks to the target object (e.g., present) upon hearing the biasing verbs (e.g., *open*) than the neutral verbs (e.g., *get*) regardless of sentence type. However, participants who listened to the complex sentences showed prediction effects somewhat later than those who listened to the simple sentences. Taken these findings together, L2 speakers are able to make use of semantic information to predict during complex sentence processing as well as simple sentence processing, but syntactic complexity may delay L2 prediction.

The semantic prediction effect during simple sentence processing is consistent with previous findings. Similar to L2 participants in Chambers and Cooke (2009), and Dijkgraaf et al. (2017), L2 speakers in this study showed prediction effects. It has been consistently reported that L2 speakers generate predictions while processing syntactically simple sentences (e.g., SVO sentences) when semantic information of the verb is manipulated. As proposed by Ito et al. (2018), this may be because such semantic information is a type of predictive cue that can be used by L2 speakers with relative ease. Computing syntactically simple sentences is not that resource-expensive, and therefore L2 speakers seem to be able to allocate resources for predictive processing. In short, L2 speakers may have enough resources for prediction during simple sentence processing particularly when semantic cues, which can be relatively easy to use, are provided.

In addition, L2 participants who processed the complex sentences in this study showed anticipatory looks to the target object before the noun could have been processed. That is, L2 speakers' predictive abilities during complex sentence processing were reaffirmed by this study in which L2 speakers were encouraged to fully parse sentences by the comprehension questions. The L2 prediction effect during complex sentence processing is therefore not likely to be due to incomplete or local parsing. The significant correlation between participants' comprehension answers and attachment interpretations in the behavioral task supports the idea that participants parsed the ambiguous RCs using their attachment bias. This finding is rather surprising given the processing difficulty that Chinese learners of English would experience when comprehending the complex sentences used in this study. Object-modifying RCs, used in the complex sentence condition, have been shown to be processed more slowly than subject-modifying RCs regardless of extraction type (Gibson et al., 2005) and L1 word order has been found to negatively influence L2 sentence processing when the word order is different between the two languages (i.e., a negative L1 transfer effect on L2 word order processing, Erdocia & Laka, 2018). Participants' L1, Chinese, has the opposite word order (e.g., RC NP1 NP2) from their L2, English (e.g., NP1 NP2 RC), and thus the Chinese learners of English who participated in this study may have experienced more processing difficulties than other L2 speakers whose L1 has the same word order as English.

L2 processing itself requires many resources, so predictive processing in L2 could be hindered by the cognitive load imposed by syntactic complexity if resources were depleted by ongoing complex linguistic computations (Mitsugi & MacWhinney, 2016). However, our findings suggest that proficient L2 speakers may have enough resources to make predictions even while they process syntactically complex sentences, at least the ones with object-modifying and subject-extracted RCs used in this study and in Chun and Kaan (2019). L2 participants in Chun and Kaan's (2019) study were Chinese learners of English who were immersed in an English-speaking country and L2 speakers in this study were Chinese learners of English in Hong Kong who use English as their official language on a daily basis. L2 speakers in these two studies not only showed similar levels of English proficiency, but they were both immersed in English-speaking environments. That is, they may have enough linguistic knowledge and cognitive resources to make predictions during online computations of complex sentences.

Though semantic prediction was observed regardless of sentence type, the time-course analysis revealed evidence for prediction during complex sentence processing somewhat later than during simple sentence processing. This finding suggests that cognitive load increased by syntactic complexity may delay predictive processing. As more resources are needed for ongoing computations of complex sentences, fewer resources could be available for predictive processing. This result is therefore compatible with Ito et al.'s (2018) findings that cognitive load delays prediction.

It should also be noted that the results of this study need to be interpreted considering the experimental manipulation. Compared to the visual displays in prior L2 research, the displays in this study were relatively complex. Previously, the visual scenes depicted four objects, one in each quadrant whereas those in this study depicted two agents and three potential themes in a semi realistic background. This visual context can be considered rather complex as a single verb has been found to activate its typical agents and patients (Kukona et al., 2011), and two agents in the visual display were equally possible for the agent of the verb (the main verb in the simple sentences and the verb embedded in the RCs). Taking into consideration its complexity, the visual display in this study was presented for two seconds (Huettig et al., 2011). In addition, participants listened to slow to normal rate of speech. These experimental settings may have enabled participants to fully perceive the visual scenes and process linguistic input to the extent that they could make predictive eye movements towards upcoming objects by integrating linguistic information with the visual scenes. Given recent findings that the speech rate and the preview time for visual displays can influence prediction in L1 comprehension (Huettig & Guerra, 2019), it is possible that predictive eye movements are less likely when L2 comprehenders are given less preview time and/or listen to faster speech. As these are other factors in the linguistic environment which can increase cognitive load during L2 comprehension, it is worth investigating the influence of these factors on L2 prediction.

Finally, this study used the same materials as those in Chun & Kaan (2019) for the complex sentence condition to compare the results between the two studies. Chun and Kaan tried to increase cognitive load during complex sentence processing using sentences containing object-modifying RCs with complex noun phrases. In fact, these sentences are not only syntactically complex but they are also globally ambiguous. The ambiguity driven from the syntactic structure may additionally increase cognitive load. Therefore, participants in the complex sentence condition may have dealt with syntactic complexity coupled with ambiguity. Their delayed prediction effect could be attributable to these factors possibly working together.

In conclusion, we reported findings from a visual world eye-tracking experiment that investigated the influence of syntactic complexity on L2 prediction. We particularly focused on syntactic complexity because it seems to be one of the most commonly encountered challenges in L2 comprehension. L2 speakers often show processing difficulty for syntactically complex sentences. Thus, we expected syntactic complexity to increase cognitive load during sentence processing and in turn influence prediction. The results of this study showed that L2 speakers made predictions on the basis of semantic information while processing complex sentences as well as simple sentences. However, their predictions were somewhat delayed during complex sentence processing. That is, L2 speakers were able to use semantic cues to predict even under increased cognitive load imposed by syntactically more complex sentences. Yet, prediction was affected by syntactic complexity as we observed some delay in prediction during complex sentence processing. These findings suggest that prediction is resource-constrained and thus L2 speakers' engagement in prediction is mediated by factors such as syntactic complexity that can influence cognitive load during sentence processing. So, it is possible that L2 speakers do not make predictions when comprehending much more syntactically complex sentences than those used in this study (e.g., ones containing embedded object-modifying and object-extracted RCs; *The fact that the president ignored the reporter who* *the senator attacked on Tuesday bothered the editor,* from Gibson et al., 2005). We call for future studies that investigate how prediction can be modulated by syntactic complexity of different complex constructions. This line of research would not only provide insights into predictive mechanisms but also help us understand why L2 speakers experience more difficulties in learning some syntactic structures than others if prediction mechanisms are indeed related to language learning.

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Table 1. Participant information

	Simple sentence condition	**Complex sentence condition**
Age	*M*: 24.24 (*SD*: 2.09)	*M*: 24.48 (*SD*: 2.35)
IELTS	*M*: 6.56 (*SD*: 0.17)	*M*: 6.60 (*SD*: 0.25)
Shipley Vocabulary Test	*M*: 21.32 (*SD*: 3.68)	*M*: 19.56 (*SD*: 3.37)
MELICET Grammar	*M*: 30.32 (*SD*: 6.14)	*M*: 29.52 (*SD*: 6.17)
Reading Span	*M*: 29.00 (*SD*: 7.75)	*M*: 29.24 (*SD*: 6.81)

Table 2. Summary of the mixed effects model as a function of verb type (Verb) and sentence type (Sentence).

	b	*SE*	*t*	*p*
Intercept	-1.38	0.15	-8.91	< 0.001
Sentence	-0.08	0.20	-0.38	0.70
Verb	0.55	0.14	3.96	< 0.001
Sentence: Verb	-0.15	0.20	-0.74	0.46

Figure 1. An example visual display

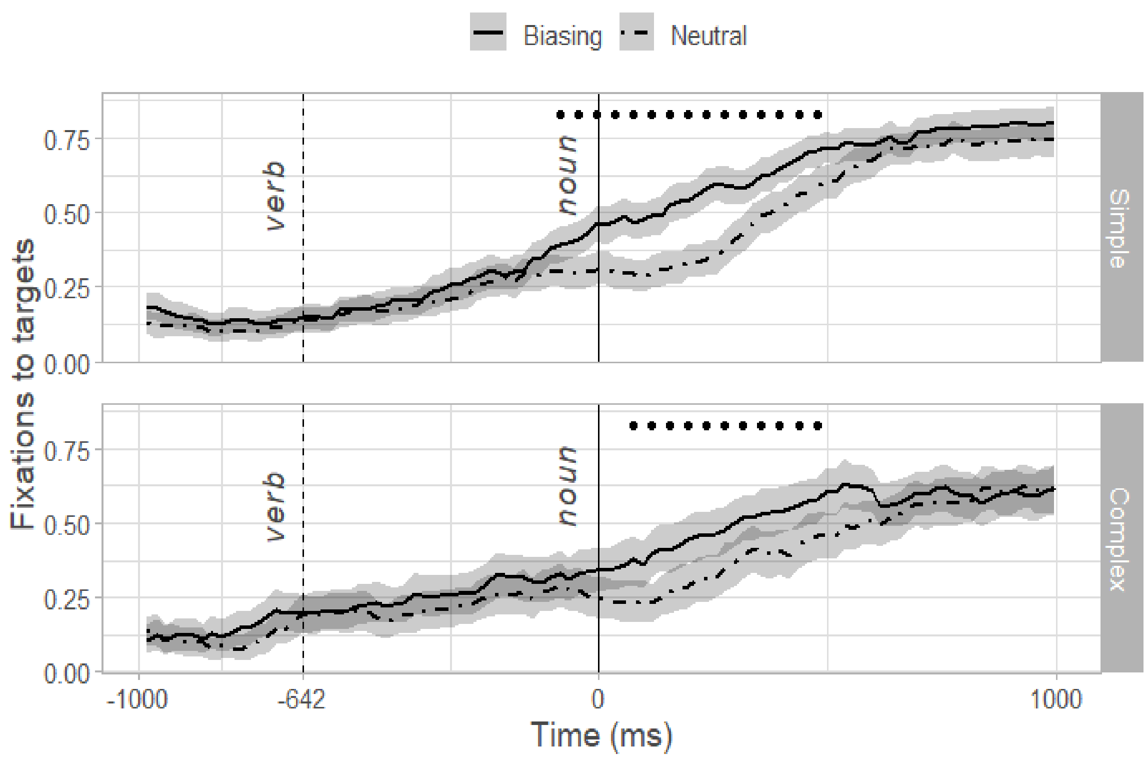

Figure 2. Mean fixation proportions to the target objects in the two verb conditions (biasing vs. neutral) in the simple sentence condition (top panel) and in the complex sentence condition (bottom panel). Error-band: 95% bootstrapped confidence intervals. A solid circle (•): significant differences in fixations on the targets between the two verb conditions in each time bin (|*t*|s > 2).