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L2 Prediction Guided by Linguistic Experience

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Research suggests that prediction is important for language comprehension and learning. Accordingly, it becomes crucial to understand factors that can influence prediction. In this regard, speakers' prior linguistic experience such as parsing bias has been claimed to affect prediction in the error-based learning account. To test this claim, the current study, using the visual world eye-tracking paradigm, investigated if L2 speakers' anticipatory eye movements are influenced by their parsing bias, and if individuals' parsing bias interacts with their working memory capacity and/or vocabulary size for the prediction. The results showed no main effect of the parsing bias on the prediction overall, and the parsing bias did not interact with the working memory capacity and/or the vocabulary size for the prediction. Importantly, however, the speakers' parsing bias significantly interacted with the trials. The influence of the parsing bias over the course of this experiment suggests that L2 speakers' prediction is guided by their recent experience with linguistic input as well as long-term linguistic experience.

Key words: L2 prediction, parsing bias, linguistic experience, the error-based learning account

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1. INTRODUCTION

Recent research suggests that comprehenders anticipate what comes next, rather than passively combine linguistic input (Altmann & Kamide, 1999; Altmann & Mirkovic´, 2009; Kuperberg & Jaeger, 2016). The findings about linguistic prediction not only retriggered important debates in cognitive science (e.g., whether human brains are automatic predictive machines; Clark, 2013), but they also expanded our understanding of language processing and learning. Traditionally, comprehension was considered to be mainly achieved in a bottom-up fashion (e.g., Forster, 1979; Marslen-Wilson, 1973); comprehenders rapidly integrate linguistic input with prior context in a highly incremental way as a sentence unfolds. However, prediction suggests that comprehension includes a great deal of top-down processing, which yields a paradigm shift in language comprehension. In addition, the findings regarding L2 prediction provide evidence that L2 processing is not fundamentally different from L1 processing (Chun & Kaan, 2019; Ito, Corley, & Pickering 2018; Kaan, 2014).

More importantly, prediction has been proposed to play a vital role in implicit learning. Chang and his colleagues successfully accounted for implicit learning of syntactic structures using the error-based learning mechanism which updates the linguistic representations by means of prediction errors (Chang, 2008; Chang, Janciauskas, & Fitz, 2012). According to this error-based learning account, speakers make predictions based on their prior linguistic experience such as parsing bias and experience prediction errors when their predictions are not met (i.e., mismatch between actual linguistic input and predictions). The prediction errors then guide the internal learning mechanisms to adjust the weights of linguistic representations in order to reduce future prediction errors. In this process, speakers adapt toward specific structures or implicitly learn those structures. In the field of second language acquisition (SLA), the notion of prediction can be used to explain the concept of “noticing the gap” which was proposed as a mechanism for L2 learning (Schmidt & Frota, 1986). L2 learners are claimed to learn better when they *notice a gap* by registering a mismatch between what they say and what their interlocutor says. L2 learners may use predictive mechanisms to notice the gap. That is, they predict what their interlocutor would say, and compare their predictions with actual speech they hear. Once they notice a gap (parallel to prediction error) and consider their interlocutor as a more proficient speaker, they trigger an adjustment of internal prediction mechanisms, which ultimately leads to L2 learning (e.g., Altmann & Mirković, 2009; Godfroid, Boers, & Housen, 2013; Huettig, 2015).

Given its important theoretical implications as laid out above, it is no surprise that prediction has drawn a great deal of recent interest in psycholinguistics and SLA. Yet, studies on L2 prediction to date have been limited to exploring whether L2 speakers can make predictions to the same extent as L1 speakers (Grüter, Lew-Williams, & Fernald, 2012; Kaan, 2014) or what types of cues can be used for L2 prediction (Chambers & Cooke, 2009; Hopp, 2016). To better understand prediction and its role in language processing and learning, more research needs to investigate which factors determine L2 prediction or under which conditions L2 speakers use predictive mechanisms. Among various factors, this study focused on *parsing bias* (shaped by individuals' long-term linguistic experience) that is proposed to influence prediction in the error-based learning account. Understanding the role of parsing bias in prediction is of great importance as it sheds light onto predictive processing in general and underlying mechanisms of implicit learning. Furthermore, the results of the current study are expected to provide some insights on L2 pedagogy, particularly relevant to comprehension (e.g., how to facilitate L2 comprehension).

2. REVIEW OF THE LITERATURE

2.1. Evidence for Prediction in Comprehension

Research provided ample evidence suggesting that comprehenders predict upcoming linguistic input, using various cues from different linguistic levels. *Prediction*[1] in this paper is defined as pre-activation of linguistic information before language input carrying that information is encountered (Pickering & Gambi, 2018). *Pre-activation* is used to refer to the linguistic information that is predictively activated. For example, when processing a sentence *The boy went out to the park to fly a kite*, if comprehenders predict *kite*, they can pre-activate some linguistic components of *kite* (e.g., conceptual feature +FLYABLE, the sound /k/, and syntactic feature NOUN). Comprehenders' pre-activation of different linguistic information has been measured using online methodologies such as eletroencephalography (EEG) or eye movements. For example, Delong, Urbach, and Kutas (2005) observed pre-activation of individual words using electrophysiological responses at the determiner (a/an) while native English participants were reading a sentence *The day was breezy so the boy went outside to fly a kite/an airplane*. When presented with highly constrained sentences leading to expectations for consonant-initial words (e.g., *kite*), the amplitude of N400 was greater for *an* (i.e., unexpected determiner) than for *a* (i.e., expected determiner). These results can be interpreted as suggesting that pre-activation of the target words can occur at the phonological level as well. In other words, participants predicted consonant-initial words (e.g., *kite*), and the phonological forms of the words were pre-

[1] There has been ongoing debate regarding prediction and pre-activation. For more discussion, see Kuperberg and Jaeger (2016).

activated with the appropriate determiner, *a* (i.e., a singular article). Accordingly, when they were presented with *an*, they would feel difficult to integrate *an* with what they expected (i.e., consonant-initial words) due to a violation of the phonological regularity in English (e.g., *a* + consonant-initial words vs. *an* + vowel initial words). The difficulty in integrating information could elicit an N400 effect (see Nieuwland et al., 2018, for different findings). In another study, Federmeier and Kutas (1999) found that semantic features of target words are pre-activated based on sentential context. They measured brain potentials while participants were reading high-constraint sentences (e.g., *They wanted to make the hotel look more like a tropical resort. So along the driveway, they planted rows of…*) completed with three different words: 1) expected words (e.g., *palms*), 2) unexpected words from the semantically same category (e.g., *pines*), and 3) unexpected words from the semantically different category (e.g., *tulips*). When the N400 amplitudes for these target words were compared, they were graded by semantic relatedness; the expected words (e.g., *palms*) elicited the smallest N400 amplitudes, and the unexpected words from the semantically same category (e.g., *pines*) elicited smaller N400 amplitudes than the unexpected words from the semantically different category (e.g., *tulips*).

Much stronger evidence for linguistic prediction came from eye-tracking studies particularly employing the visual world paradigm (VWP) in which researchers track listeners' eye movements on the visual displays while they listen to linguistic input (Huettig, Rommers, & Meyer, 2011). In such studies, participants are asked to preview the visual displays for a short time (1–2 sec) and then listen to auditory stimuli in sync with the displays. The visual displays typically contain a target (an object that is directly mentioned in the experimental speech), a competitor (an object that has a similar property or feature to the target) and distractors (objects that are not related to the target). In this paradigm, language users align their eye movements with the speech they hear or shift their attention associated with the speech, and thus their fixations on the target objects increase upon hearing the target words (Cooper, 1974). In one of the earliest eye-tracking studies, Altmann and Kamide (1999) found that comprehenders show anticipatory looks to the target objects *even before* they hear the predictable words (i.e., the target words). They measured participants' looks onto the items of visual displays—a target (e.g., a cake) and distractors (e.g., a ball, a toy train, and a toy car)—while listening to simple sentences with either semantically restrictive verbs (e.g., *The boy will eat a cake*) or non-restrictive verbs (e.g., *The boy will move a cake*). When the eye fixations were compared between these two verb conditions, the fixations on the target object (e.g., a cake) appeared significantly earlier when hearing restrictive verbs (e.g., *eat*) than when hearing non-restrictive verbs (e.g., *move*). These results suggest that comprehenders can use semantic information of the verbs to predict upcoming input (e.g., a cake*;* something with +EATABLE feature). As such, the visual world eye-tracking experiments clearly reveal comprehenders' anticipatory eye movements during language processing and thus provide strong evidence for linguistic prediction. To date, this eye-tracking methodology has been widely used in prediction studies (see Huettig, 2015; Kuperberg & Jaeger, 2016, for recent reviews), and those studies have reported that L1 comprehenders generate predictions making use of various linguistic cues: semantic features (Altmann & Kamide, 1999), morpho-syntactic features (Dahan, Swingley, Tanenhaus, & Magnuson, 2000; Kamide, Altmann, & Haywood, 2003), and prosodic features (Nakamura, Arai, & Mazuka, 2012).

2.2. Prediction in L2 Comprehension

The findings of linguistic prediction in L1 comprehension prompted research on L2 prediction. Thus far, studies on L2 prediction have primarily addressed the questions of whether L2 speakers can predict, and if so, whether they predict to the same extent as L1 speakers, or what types of linguistic information L2 speakers can use for prediction. Current literature on L2 prediction seems to reach consensus on L2 speakers' ability to predict, but the extent of L2 prediction differs depending on linguistic cues or cognitive demands for the task at hand. When semantic cues are available, L2 speakers can easily make use of the cues and predict to a similar extent as L1 speakers (Dahan et al., 2000). For example, Chambers and Cooke (2009) replicated the semantic prediction (Altmann & Kamide, 1999) in L2 speakers. In a visual world eye-tracking study, they found that late L2 French learners made more anticipatory eye movements onto *poule* (chicken) when hearing the verb *nourrir* (feed) compared to when hearing the verb *décrire* (describe) from a sentence *Marie will feed/describe the chicken.* This type of semantic cue (e.g., restrictive verb information) is readily used for prediction even when L2 speakers process complex sentences that require more cognitive resources (Chun & Kaan, 2019) or when L2 speakers' proficiency is at the beginning level (Koehne & Crocker, 2015). Similarly, Dijkgraaf, Hartsuiker, and Duyck (2016) found that unbalanced Dutch-English bilinguals could predict using semantic information to the same extent in both L1 and L2, and their predictive processing in L1 was not different from monolinguals. Taken these results together, L2 speakers are more likely to generate predictions using semantic information when it is available in the linguistic context.

As for the use of (morpho)syntactic cues, however, the reported findings are mixed. Some of early studies found no prediction effect in L2 speakers though they have relevant L2 grammatical knowledge (Dussias, Kroff, Tamargo, & Gerfen, 2013; Lew-Williams & Fernald, 2010). Dussias et al. (2013) investigated whether Spanish L2 learners of English can use grammatical gender agreement in Spanish as predictive cues. Moderately proficient L2 participants in their study knew the rule of gender agreement in Spanish but could not use the information predictively. Furthermore, in an ERP study employing a similar paradigm to Delong et al.'s (2005) study, Martin et al. (2013) did not find modulated N400 effect in English-L1 and Spanish-L2 speakers for the case of mismatches between the determiner (e.g., *an*) and the expected noun (e.g., *kite*). On the other hand, the picture emerging from recent studies suggests that L2 speakers are able to predict using (morpho)syntactic cues, but this type of prediction is influenced by several factors such as similarity in linguistic properties between L1 and L2. L2 speakers are more likely to predict when L2 has similar syntactic features to their L1 (Foucart, Martin, Moreno, & Costa, 2014) whereas they have difficulties in predicting when L2 has different syntactic features from their L1 (Dussias et al., 2013; Lew-Williams & Fernald, 2010). When L1 and L2 have similar grammatical rules, syntactic prediction seems possible in L2 regardless of L2 speakers' proficiency. Both early Spanish-Catalan bilinguals and late French-Spanish bilinguals could use morpho-syntactic rules to predict upcoming nouns to the same extent as Spanish monolinguals; the N400 effect was modulated in case the grammatical gender of an article did not match that of a noun (Foucart et al., 2014). Van Bergen and Flecken (2017) also provided evidence for the L1 effects on syntactic prediction. They tested whether L2 speakers with different L1 backgrounds (English, French, and German) can use L2 syntactic information for prediction (e.g., predicting object positions using Dutch placement verbs). Their results showed that only German learners whose L1 similarly encodes syntactic information could predict object positions using Dutch placement verbs.

2.3. Factors Influencing Prediction

Identifying individual differences has been important in language processing and learning in general. It also holds true for research on prediction as predictive processing is graded depending on linguistic and cognitive factors (Kaan, 2014). First, speakers' proficiency has been pointed out to influence their predictive ability. A certain quality of linguistic knowledge should be acquired for learners to make use of that information for prediction. In this regard, Kukona et al. (2016) found that L1 speakers' semantic prediction was highly related to their comprehension ability (a composite score of listening and reading comprehension and vocabulary knowledge), decoding and fluency in reading, and rapid automatized naming. Similarly, Borovsky, Elman, and Fernald (2012) reported that L1 speakers' vocabulary size can determine their prediction strength (in both children and adults). The same idea is true for L2 speakers. In Dussias et al.'s (2013) study, gender-based prediction was not found in moderately proficient L2 speakers, but highly proficient L2 speakers in the same study could predict in a nativelike way even though their L1 English does not possess similar syntactic features to L2 Spanish. In addition, Hopp (2014) reported that L2 speakers' gender-based prediction was related to gender assignment abilities and lexical access speed. In another study using a pre- and post-test design, Hopp (2016) also found that gender assignment training can help L2 speakers (English learners of German) use gender information for prediction.

Prediction is further modulated by speakers' cognitive resources. Ito, Corley, and Pickering (2018) found that a cognitive load delays prediction in L1 as well as in L2. Using the visual world eye-tracking paradigm, they compared participants' predictive eye movements to the targets (e.g., scarf) while listening to sentences with semantically biasing verbs (e.g., *The lady will fold the scarf*) vs. those with non-biasing verbs (e.g., *The lady will find the scarf*). Half of the participants in each language group performed an additional memory task (e.g., remembering words). In both groups, participants showed more anticipatory fixations to the target objects when listening to sentences with semantically biasing verbs than when listening to those with non-biasing verbs. However, the prediction effect was delayed in both groups of participants who performed an additional memory task. Importantly, L2 processing in nature is more cognitively taxing than L1 processing (Hopp, 2014; Kaan, 2014). Hence, prediction can be much more challenging to L2 speakers when a cognitive load is increased during sentence processing. L2 speakers may have to use up their resources for ongoing processing (e.g., retrieving linguistic information from memory and combining incremental input for comprehension), and thus leave little or no resources for prediction. This idea was supported by Chun and Kaan's (2019) finding that L2 prediction was a bit (180ms) delayed than L1 prediction under the condition which cognitive load is internally increased to sentence processing (e.g., complex sentence processing).

Last but not least, individuals' parsing bias has been proposed to influence prediction in the error-based learning account. Speakers obtain a different parsing bias depending on their prior linguistic experience (i.e., to which linguistic environment they have been exposed). For example, readers typically experience processing difficulty for a reduced relative clause structure (e.g., *The soldiers warned about the dangers conducted the midnight raid* from Fine, Jaeger, Farmer, & Qian, 2013), and their difficulty is evidenced as lengthened reading times for the disambiguating region (*conducted*). It is because main clause sentences are far more frequent than reduced relative clause sentences, which develops a parsing bias towards main clause sentences. Therefore, while processing a reduced relative clause sentence, readers first parse it as a main clause sentence, but realize that their initial parsing is incorrect upon encountering *conducted*. They then revise their initial parsing, and this revision process increases reading times for reduced relative clauses. Interestingly, however, reading times for reduced relative clauses decrease with repeated exposure to the same structure (Fine & Jaeger, 2013; Fine et al., 2013). This kind of linguistic phenomena is known as syntactic adaptation and notably, adaptation effect has been found to be greater for less frequent/preferred structures than for frequent/ preferred structures. This finding, dubbed the inverse frequency/preference effect, has also been observed in cumulative syntactic priming which lasts over several days and is thus considered to be implicit learning of syntactic structures (Bernolet & Hartsuiker, 2010; Kaan & Chun, 2018; Kaschak, Kutta, & Schatschneider, 2011). The inverse frequency/ preference effect can be accounted for using prediction errors in the error-based learning account. As comprehenders predict using parsing bias, they experience more prediction errors while processing less preferred/frequent structures. More prediction errors then trigger greater change in the linguistic representations, which results in greater adaptation or cumulative priming (implicit learning). As such, the inverse frequency/preference effect provides indirect evidence for the effects of parsing bias on prediction.

3. METHODOLOGY

3.1. The Current Study

In addition to the inverse frequency/preference effect, prediction literature provides some insights to the potential relationship between linguistic experience and prediction. L2 speakers have been shown to predict using specific syntactic information once they have enough experience relevant to the information either in L1 (e.g., L1 transfer effects) or in L2 (e.g., proficiency or exposure duration). However, it is still unknown whether L2 speakers' parsing bias, shaped by their long-term linguistic experience in L2, influences their prediction during comprehension. This study therefore investigated the effects of L2 parsing bias on prediction. Furthermore, this study investigated whether individuals' parsing bias interacts with their working memory capacity and/or vocabulary size to modulate L2 prediction. These individual difference factors were included as 1) L2 processing in and of itself is more taxing than L1 processing and thus L2 processing in general is affected by individuals' working memory capacity (Hopp, 2014; Kaan, 2014), 2) further cognitive resources are assumed to be required for predictive mechanisms while L2 speakers incrementally process linguistic information (Kaan 2014), and 3) learners' vocabulary size is found to modulate prediction even in L1 speakers (Borovsky et al., 2012). The concrete research questions for this study are therefore as follows:

1. Does L2 speakers' parsing bias influence prediction in comprehension?
2. Does individuals' parsing bias interact with their working memory capacity and/or vocabulary size to modulate L2 prediction?

This study consisted of two stages: a pre-test to identify participants' parsing bias and the visual world eye-tracking task to measure their use of parsing bias for prediction. Participants' different parsing bias was measured using ambiguous relative clause (RC) sentences at the pre-test. For example, in a sentence like *Someone shot the servant of the actress who was on the balcony*, the RC can be attached to either the first noun phrase (NP1, *the servant*) or the second noun phrase (NP2, *the actress*). However, speakers vary in terms of attachment bias depending on their cumulative linguistic experience. For example, native speakers of English mostly prefer attaching the RC to the NP2 (NP2 attachment or low attachment; Frazier & Clifton, 1997) whereas Spanish speakers prefer attaching the RC to the NP1 (NP1 attachment or high attachment). Also, research has shown that this attachment bias changes according to speakers' linguistic experience. Spanish-L1 and English-L2 speakers who initially showed NP1 attachment preference (influenced by L1 transfer) changed their bias towards NP2 attachment, aligning with preference of native English speakers after spending more than 7 years in the immersion environment (Dussias & Sagarra, 2007). These findings suggest that RC attachment bias reflects speakers' long-term linguistic experience.

To measure prediction, this study employed the visual world eye-tracking paradigm in which participants look at the visual displays while listening to auditory sentences. The RC attachment sentences are chosen for the eye-tracking task as well. In a previous study, Chun and Kaan (2019) tested this type of complex construction for L2 prediction and found that L2 speakers can generate predictions while processing ambiguous RC sentences. For example, L2 participants predicted an openable item, showing anticipatory fixations to the *present* upon hearing the verb *open* from a sentence *I know the friend of the dancer that will open the present*. Hence, this type of construction can be used to investigate whether L2 speakers use their parsing bias to predict if the RCs are manipulated to be semantically biased towards one attachment, either NP1 attachment or NP2 attachment. Note that the ambiguous RC attachment construction does not inform us of listeners' use of parsing bias because either attachment would lead to anticipatory looks onto the same object. Therefore, the RCs were manipulated to be semantically biased towards NP2 attachment (e.g., *I see the uncle of the girl that will ride the rocking horse*). If L2 speakers have NP2 attachment bias and use the bias to predict (as claimed in the error-based learning account), they would show anticipatory looks to something for *the girl* to ride (e.g., the rocking horse) upon hearing the verb '*ride'* whereas those with NP1 attachment bias would show anticipatory looks to something for *the uncle* to ride (e.g., the motorbike). That is, it was expected that participants would show more anticipatory fixations onto to the target (e.g., the rocking horse) than the competitor (e.g., the motorbike) as they are more biased towards NP2 attachment bias and use the bias for prediction.

Under the error-based learning account, it was expected that the more biased towards NP2 attachment, the more anticipatory fixations onto the targets (e.g., the rocking horse) than the competitors (e.g., the motorbike) overall. This pattern was further expected to be clearly observed from the beginning of the experiment, not being changed until the end, for those with stronger NP2 attachment bias as they would hear what they expect (i.e., rare prediction error experienced). On the other hand, those with weaker NP2 attachment bias were expected to experience some prediction errors at early trials of the experiment when using their bias for prediction, and accordingly change their predictions over time aligning with the target structures (NP2 attachment).

3.2. Participants

Twenty-one native speakers of English[2] (male = 5; age =18 – 28, M_{age}= 19.86, *SD* = 2.06) and twenty-one Chinese learners of English (male = 7; age 18 – 28, M_{age} = 23.14, *SD* = 2.85) participated in this study for monetary compensation ($7.50 per hour). Both groups of participants were recruited from University of Florida, and the L2 participants also resided in the USA at the time of this study (age of L2 acquisition: *M* = 7.4 years old, *SD* = 1.95; duration of immersion: *M* = 10.8 months, *SD* = 11.2). They all had normal or corrected-to-normal vision, and none of them reported hearing problems or learning disorders. Before the experiment, they completed an informed consent form approved by University of Florida Institutional Review Board (IRB201700448). Two groups differed in proficiency ($t(25.2) = 8.13$, $p < .001$) at the grammar and cloze section of MELICET (Michigan English Language Institute College English Test); L1 participants showed higher proficiency (*M* = 45.48 out of 50, *SD* = 2.29) than L2 participants (*M* = 33.57, *SD* = 6.31).

3.3. Materials

3.3.1. The pre-test

For the pre-test, three lists of ambiguous RC sentences were prepared to determine individuals' parsing bias. Each list consisted of 12 ambiguous RC sentences (e.g., *Michelle sees the child of the mother that is talking to the woman*) and 16 fillers which contained RC with one NP (e.g., *The banker sees the customer that is using the phone*). The materials for the pre-test were recorded by a female native English speaker using a Marantz PMD660 Digital Recorder. Ence was recorded three times using 16-bit stereo PCM sound at a sampling rate of 44.1 kHz with an external head mounted microphone. Considering speech rate and sound quality, the best version was chosen and edited using Praat audio editing software (Boersma & Weenink, 2016). Some manipulation was done to prevent any

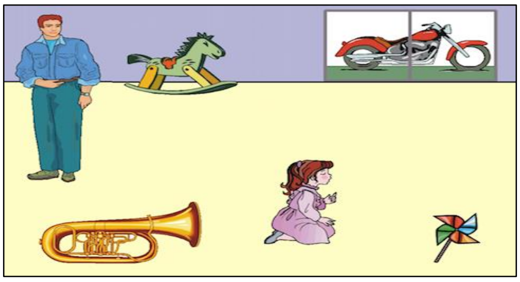
[2] The L1 data presented here were collected for another study. The data from the first twenty-one participants were taken for the purpose of comparison.

prosodic influence[3] (e.g., prosodic boundary and pitch accents). Pauses were deleted 1) between NP1 (e.g., *the child*) and *of*, 2) between *of* and NP2 (e.g., *the mother*), and 3) between NP2 and *that*. Then, the pitch of the two NPs in each sentence was equalized, and all the sound files were normalized using the mean intensity (M = 74.91 dB). After editing the sound files, the naturalness of the resultant auditory stimuli was judged and confirmed by ten listeners who did not know the purpose of this study.

3.3.2. The visual world eye-tracking task

For the eye-tracking task, the materials of Kamide's (2012) study were modified. Two sets of 28 experimental sentences were prepared by counterbalancing two NPs. They contained the RCs which were semantically biased towards the NP2 attachment (e.g., *I see the uncle of the girl that will ride the rocking horse*). Thirty RC sentences with one NP were created for fillers. In addition, two sets of 14 pictures were created to be presented with the experimental sentences; the sets only differed in the positions of picture items. As shown in Figure 1, each picture contained two possible agents (e.g., the man and the girl), two potential themes—the target (e.g., the rocking horse), and the competitor (e.g., the motorbike)—and two distractors (e.g., the tuba and the pinwheel). All the sentences for the eye-tracking task were recorded and edited in the same way as those for the pre-test. In addition, the duration of the target region (e.g., verb + *the*: 526 ms) was equalized using the mean duration of all the target regions to ensure that participants can be given the same amount of time to use the semantic information of the verbs to anticipate the target in each sentence. Finally, all the sound files were normalized using the mean intensity (M = 74. 63 dB).

FIGURE 1
An Example of the Visual Display



Source: Chun, E. (2018). *The role of prediction in adaptation: An evaluation of error-based learning accounts.* Unpublished doctoral dissertation, University of Florida, Florida.

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[3] This process was done for the sake of understanding the parsing bias effect clearly. Given prosodic cues become available before any other cues, participants could make use of prosodic cues for prediction, which then would create confounded results.

3.4. Procedure

3.4.1. The first stage: The pre-test

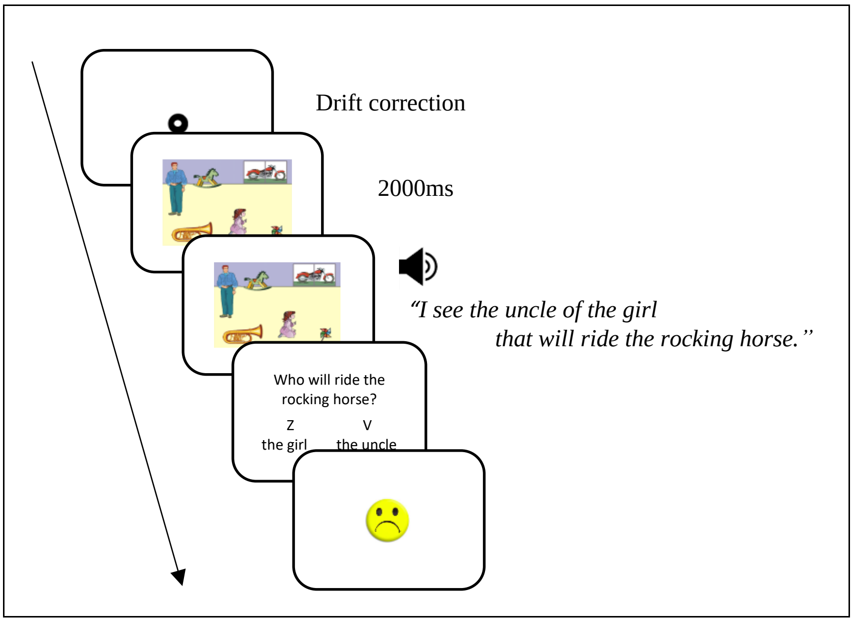
The pre-test was administered using E-prime 2.0 professional (Psychological Software Tools). Three lists of the pre-tests were counterbalanced across the participants, and auditory sentences in each list were pseudorandomized, with the fillers intermixed after one or two experimental sentences. In the pre-test, participants listened to auditory sentences (e.g., *Michelle sees the child of the mother that is talking to the woman*) via headphones and answered comprehension questions (e.g., *Who is talking to the woman?*) asking where to attach the RCs. They answered by pressing button “1” or “2” which corresponds to the NP1 or the NP2. For the answer choices, half of “1” were matched with the NP1 (e.g., *the child*) and the other half of “1” were matched with the NP2 (e.g., *the mother*).

3.4.2. The second stage: The visual world eye-tracking task

In the eye-tracking task, participants were worn a head-mounted eye-tracker (Eyelink 2 version 2.21, SR research, Mississauga, Ontario, Canada) after sitting in a comfortable chair 70 cm apart from a computer screen. After camera setup, an automatic 9-point calibration and validation routine was done using a standard black and white 20-point bull’s-eye image. The visual stimuli were presented at a resolution of 1024 × 768 pixels using a PC computer running EyeLink Experiment Builder software (SR Research, Mississauga, Ontario, Canada) and auditory stimuli were presented using the same computer via headphones. While listening to auditory sentences, participants’ eye movements were recorded at 500 Hz sampling rate. Participants were given five practice trials before the main experiment and practiced with them until they fully understood the task.

Each trial in the eye-tracking task started with a bull’s-eye image at the center of the screen (see Figure 2 for the experimental procedure). The dot served as a drift correction. Participants were asked to fixate onto it and press the keyboard to proceed to the trial. Once the keyboard was pressed, a visual display appeared for 2000 ms (cf. Huettig, Rommers, & Meyer, 2011). The visual display remained on the screen after auditory sentence offset until participants clicked on the last mentioned item from each sentence. The mouse-clicking task was to get participants engaged in the task as well as to make their eye movements aligned with processing of the auditory stimuli. After listening to auditory sentences, participants answered comprehension questions (e.g., *Who will ride the rocking horse?*) by pressing the button Z or V which correspond to NP1 or NP2. These comprehension questions were included to make them alert during the task. Two thirds of the experimental sentences were followed by the comprehension questions and a sad face was provided only when their answer was incorrect (i.e., NP1 attachment).

FIGURE 2
The Flow of an Experimental Trial in the Eye-Tracking Task



Source: Chun, E. (2018). *The role of prediction in adaptation: An evaluation of error-based learning accounts.* Unpublished doctoral dissertation, University of Florida, Florida.

3.4.3. Behavioral tasks

Finally, a battery of behavioral tasks was administered using E-prime: the vocabulary section of the Shipley Institute of Living Scale[4] (Shipley, Gruber, Martin, & Klein, 2009) to measure participants' vocabulary size and an auditory version of digit span task (Wechsler, 1997) to measure their working memory capacity. There were 40 questions in the Shipley vocabulary test, and 24 trials of digit span tasks (12 trials of forward digit span and 12 trials of backward digit span). After all the tasks, participants completed the debriefing questions.

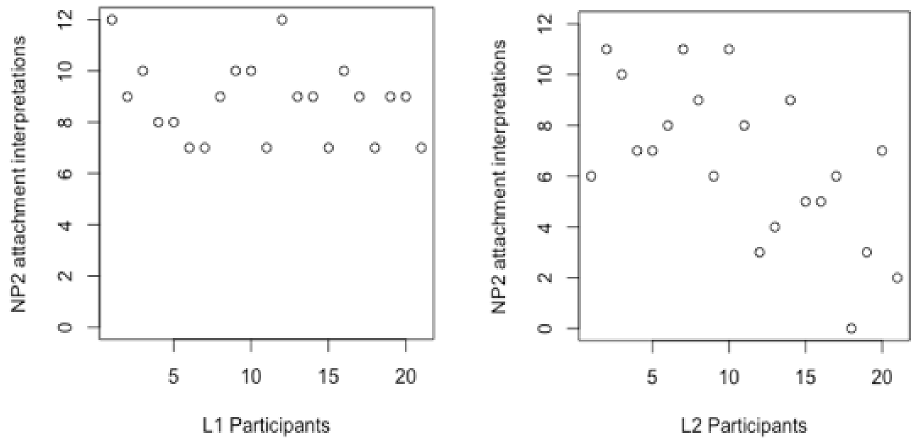
4. RESULTS

For the analysis, individuals' parsing bias was quantified by calculating participants' NP2 attachment interpretations at the pre-test. One point was awarded for each NP2 attachment interpretation (out of 12 sentences), and this means that the higher score, the stronger NP2

[4] This vocabulary test was selected not only due to its validity, but also to avoid the ceiling effects. Most well-known vocabulary tests including LexTALE have shown the ceiling effects in young adult speakers, which makes it difficult to investigate individual difference effects.

attachment bias and the lower score, the stronger NP1 attachment bias. Figure 3 plots an individual participant's parsing bias towards NP2 attachment in each group. As in Figure 3, most speakers in both groups were biased towards NP2 attachment, with L2 group showing more variance (range 0–11, *M* = 6.57, *SD* = 3.08) than L1 group (range 7–12, *M* = 8.81, *SD* = 1.54). Then, the linguistic and cognitive behavioral tasks were scored. The results of these tasks showed that two groups differed in vocabulary size ($t(38.47) = 6.26$, $p < .001$; L1 group, *M* = 31.57, *SD* = 3.26; L2 group, *M* = 24.52, *SD* = 4), but not in working memory capacity ($t(39.62) = 1.59$, $p = .12$; L1 group, *M* = 16.86, *SD* = 3.15; L2 group, *M* = 15.38, *SD* = 2.85).

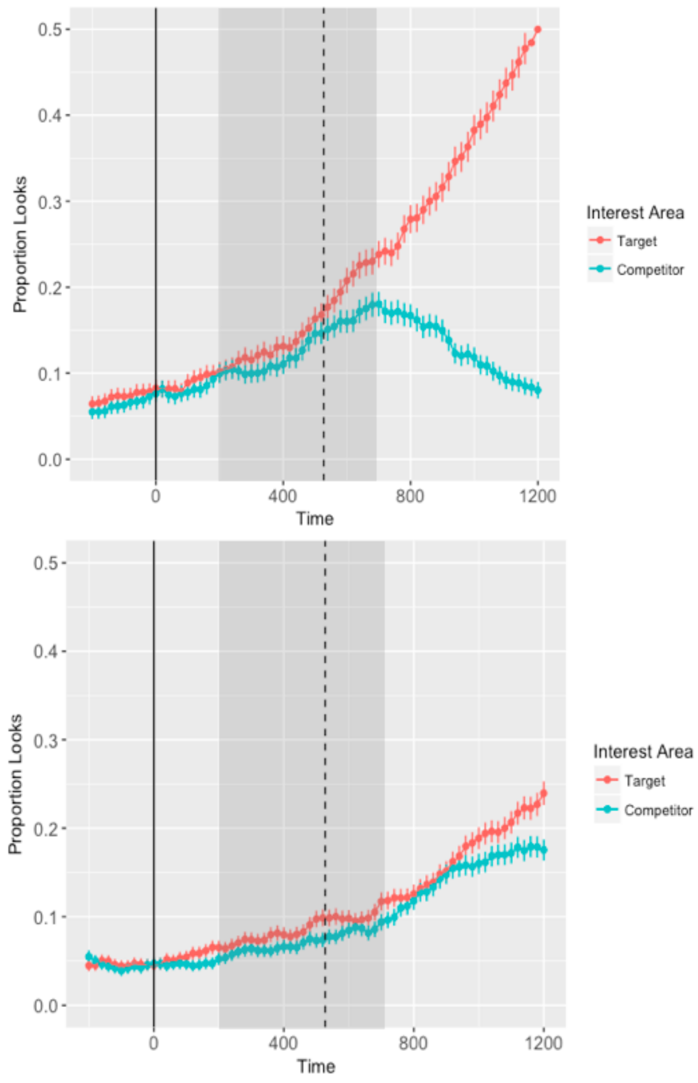
FIGURE 3
Participants' Parsing Bias in L1 Group (Left Panel) and L2 Group (Right Panel)



As for the eye-tracking data, the accuracy of mouse-clicking data and comprehension answers was first checked. Participants showed high accuracy in the mouse-clicking responses (L1 group 99.8%; L2 group 96%) and the comprehension answers (L1 group 94.2%; L2 group 90%), indicating that they were fully engaged in this task. For the main analysis, the trials with incorrect mouse clicking responses and comprehension answers were excluded. This exclusion process yielded 11.5% data loss in total. Then, using the VWPre package (Porretta et al., 2017) in R (R Core Team, 2016), fixation proportions on the targets and the competitors were calculated for each 20ms time bin relative to the onset of the verb. Figure 4 plots overall fixation proportions on the targets (e.g., the rocking horse) and the competitors (e.g., the motorbike) while participants were listening to the target region (verb + *the*). The time is synchronized to the verb onset (at 0 ms) and the time window is set from -500 ms (i.e., 500 ms before the verb onset) to 1200ms to show eye fixations during the critical time for prediction (i.e., 200–726 ms post-verb onset). Figure 4 reveals that participants started to show more fixation proportions on the targets than on the competitors upon hearing the verb (i.e., greater anticipatory looks to the targets even before hearing the target noun); the difference in fixation proportions between the targets and the competitors seemed larger in L1 group than in L2 group.

FIGURE 4

Fixation Proportions on the Targets (e.g., the rocking horse) and the Competitors (e.g., the motorbike)



Note. L1 group (top panel) and L2 group (bottom panel). solid vertical line = onset of the verb (e.g., *ride*); dotted vertical line = onset of the target noun; the gray region = predictive looks while listening to the verb + *the*; error-bars = 95% confidence intervals

To examine whether this difference in fixation proportions is significantly influenced by parsing bias (i.e., the effects of parsing bias on prediction), a linear mixed effects model was constructed on target advantage scores. The target advantage scores (the dependent variable) were calculated using the difference in fixation proportions between the targets and the competitors during the critical time window (i.e., 200–726 ms post-verb onset). This time window was set as eye movements reflecting language processing are known to begin approximately 200ms after listening to auditory stimuli and the duration of the target region (e.g., verb + *the*) was 526 ms (note that prediction can be made before they hear the target noun, *rocking horse*). Positive values of the target advantage scores indicate more fixations on the targets than on the competitors whereas negative values of the target advantage scores indicate more fixations on the competitors than on the targets. In this model, the fixed factors were dummy coded group (L1 coded as reference vs. L2), centered parsing bias (i.e., NP2 attachment bias scores from the pre-test), trials, and a full set of interactions among these fixed factors. A fixed factor of trials was included as participants' prediction could be changed over the trials with repeated exposure to the same construction (i.e., the effects of recent linguistic experience with NP2 attachment construction). For the random effects, random intercepts were included for participants and items.

The results of this linear mixed effects model are summarized in Table 1. As shown in Table 1, there was no main effect of the parsing bias on the predictive looks to the targets. However, the parsing bias significantly interacted with the trials in each group (L1 group, b = 0.00, SE = 0.00, t = 5.99, p < .001; L2 group, b = -0.00, SE = 0.00, t = -4.65, p < .001).

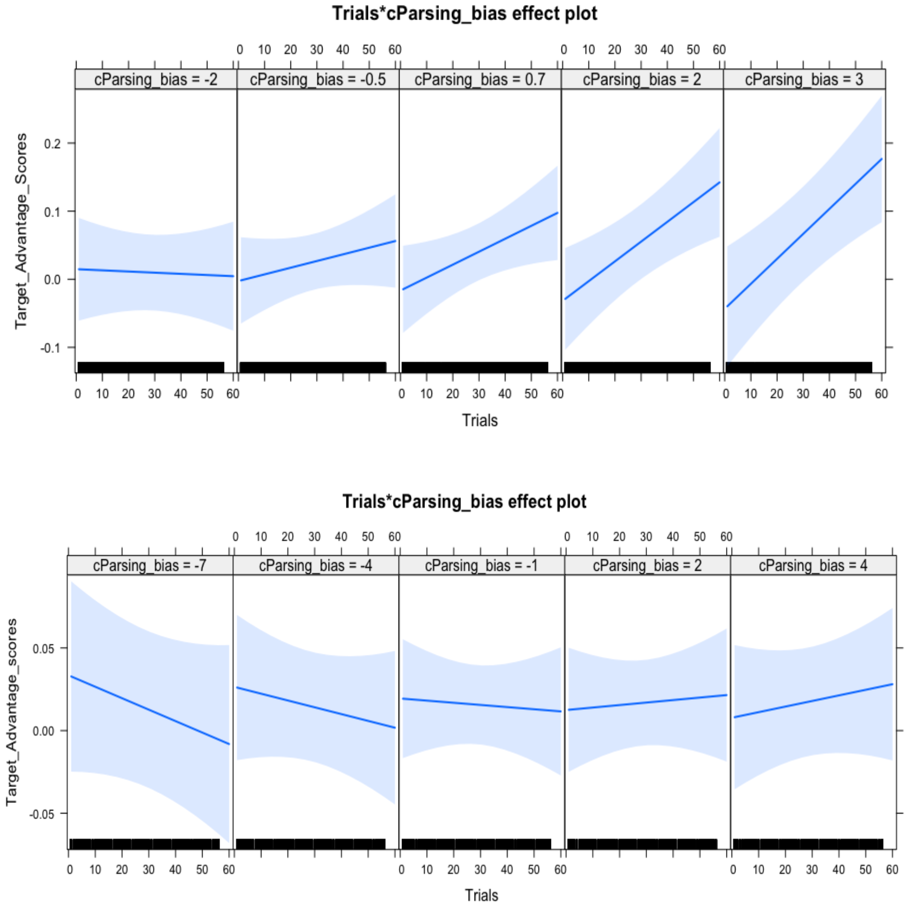
TABLE 1

Target Advantage Scores as a Function of Group, Parsing Bias, and Trials

Fixed Effects:	*b*	*SE*	*t*	*p*
(Intercept)	0.00	0.02	0.08	.94
Parsing Bias	-0.01	0.01	-1.34	.19
Trials	0.00	0.00	0.81	.42
L2 Group	0.01	0.02	0.62	.54
Trials : Parsing Bias	0.00	0.00	5.99	< .001
L2 Group : Trials	-0.00	0.00	-1.29	.20
Parsing Bias : L2 Group	0.01	0.01	0.85	.40
Trials : Parsing Bias : L2 Group	-0.00	0.00	-4.65	< .001

The interaction effects for each group are plotted in Figure 5. As in Figure 5, these interaction effects revealed that both L1 and L2 participants made more anticipatory looks to the targets than to the competitors over the trials as they were more biased towards NP2 attachment.

FIGURE 5
The Interaction Effects Between Trials and Parsing Bias for L1 Group (Top Panel) and L2 Group (Bottom Panel)



To investigate potential interactions between parsing bias and vocabulary size and/or working memory capacity, a separate linear mixed effects model was constructed on the target advantage scores for each group. The fixed factors were parsing bias, a two-way interaction between parsing bias and vocabulary (i.e., Shipley vocabulary scores), another two-way interaction between parsing bias and working memory capacity (i.e., digit span scores), and a three-way interaction between parsing bias, vocabulary, and working memory capacity. All these fixed factors were centered. For the random effects, random intercepts were included for participants and items. According to the results, there was no significant effect of any fixed factors (see Table 2 for the summary of these models).

TABLE 2

Target Advantage Scores as a Function of the Interactions Between Parsing Bias and Vocabulary and/or Working Memory Capacity for Each Group

L1 Group				
Fixed Effects:	*b*	*SE*	*t*	*p*
(Intercept)	0.03	0.02	1.28	.21
Parsing Bias	0.01	0.01	0.98	.34
Parsing Bias : Vocabulary	-0.00	0.00	-0.32	.75
Parsing Bias : Working Memory	-0.00	0.00	-0.81	.43
Parsing Bias : Vocabulary : Working Memory	0.00	0.00	0.27	.79
L2 Group				
Fixed Effects:	*b*	*SE*	*t*	*p*
(Intercept)	0.01	0.01	0.70	.49
Parsing Bias	0.00	0.00	0.73	.47
Parsing Bias : Vocabulary	-0.00	0.00	-1.72	.10
Parsing Bias : Working Memory	-0.00	0.00	-1.70	.11
Parsing Bias : Vocabulary : Working Memory	0.00	0.00	0.84	.41

5. DISCUSSION AND CONCLUSION

The error-based learning account posits that speakers predict based on their previous linguistic experience such as parsing bias and experience prediction errors when actual linguistic input disconfirms their predictions. Implicit learning is then proposed to occur in the process speakers adjust linguistic representations to minimize such prediction errors. Likewise, prediction based on speakers' prior cumulative experiences (e.g., parsing bias) is a core assumption of the error-based learning account and understanding the relationship between parsing bias and prediction has important theoretical implications not only for predictive processing in general but also for language learning. Some previous findings provided indirect evidence for this assumption (i.e., prediction affected by long-term linguistic experience). L2 syntactic prediction was modulated by L1 linguistic experience (i.e., L1 transfer effects) or L2 linguistic experience (e.g., proficiency or L2 exposure duration). In addition, greater adaptation or learning effect was found for the less preferred/ frequent structures than the preferred/frequent structures, and this so-called inverse preference/frequency effect could be explained using greater prediction error experienced for the less preferred or less frequent structures. If prediction is truly guided by speakers' prior linguistic experience, as claimed in the error-based learning account, parsing bias shaped by individuals' long-term linguistic experience would influence predictive processing.

With the aim of testing this core assumption, the current study investigated the effects of parsing bias on prediction. Using ambiguous RC sentences, this study first identified participants' parsing bias towards RC attachment and then measured prediction influenced by parsing bias using the visual world eye-tracking paradigm. Under the error-based learning account, it was expected that the more biased towards NP2 attachment, the more anticipatory fixations onto the targets (e.g., the rocking horse) than the competitors (e.g., the motorbike) overall. For those with stronger NP2 attachment bias, this prediction pattern was expected to appear from the beginning of the experiment and remain unchanged as they would rarely experience prediction errors while processing NP2 attachment sentences (i.e., they supposedly hear what they expect). On the other hand, those with weaker NP2 attachment bias were expected to change their predictions over time aligning with the target structures (NP2 attachment) after experiencing some prediction errors at early trials of the experiment.

The current data showed that participants' predictive looks were not significantly influenced by their parsing bias overall. Importantly, however, the influence of participants' parsing bias on the prediction increased over time in both groups: The more biased towards NP2 attachment, the more anticipatory fixations onto the targets than the competitors over the course of the experiment. These findings suggest that L2 speakers as well as L1 speakers make use of parsing bias for predictive processing, as claimed in the error-based learning account. However, the pattern was not consistent with what was expected under the error-based learning account. Those with stronger NP2 attachment bias significantly used their bias for prediction as they were increasingly exposed to the NP2 attachment sentences (i.e., influence of recent experience with linguistic input).

These results seem difficult to classify as a task effect or they cannot be simply explained as any sort of reinforcement from the feedback. Note that participants in this study were not explicitly instructed to make predictions in the task. Even if they could get used to the experimental task or sentences, their ability to generate predictions is another issue. In addition, the feedback, which was designed to engage participants in the task, was only presented when their answers were wrong. Given the high accuracy of comprehension answers in both groups, they rarely got the sad face feedback. In fact, the sad face feedback simply indicated their answer was wrong, not providing any detailed information which would encourage their processing in a specific way. The results of this study therefore cannot be solely attributable to the task effect or the reinforcement from the feedback.

Rather, this pattern can be better accounted for using the utility-based framework (Kuperberg & Jaeger, 2016) in which language users as resource-bound rational beings would predict if predicting can maximize processing efficiency for comprehension. In other words, language users are likely to predict evaluating advantages and disadvantages of prediction during comprehension. They can evaluate predictive processing using availability and reliability of cues. Once a cue is assessed to be available and reliable, the cue is more likely to be used for predictive processing to maximize processing efficiency for comprehension. This study only used NP2 attachment structures and the cues of semantic associations between the verbs (e.g., *ride*) and the NP2s (e.g., *the girl*) were consistently available and reliable for prediction in the given experimental context. Therefore, it is possible that those with stronger NP2 attachment bias could evaluate predictive cues rather quickly as the semantic association cues were consistent with their parsing bias. They may be able to evaluate reliability and validity of the predictive cues through recent linguistic experience with NP2 attachment during early trials and then increasingly use their parsing bias (parallel to semantic cues) to predict as prediction using their parsing was considered efficient.

Some may point out the cases that participants with NP2 attachment bias would show anticipatory looks to the competitors (e.g., the motorbike) during early trials as the competitors shared semantic features (+ RIDABLE) with the targets (e.g., the rocking horse). This kind of case could happen when they only focused on the verb information to predict the upcoming object, not attaching the RC to either noun phrase (i.e., when they did not fully parse sentences), or when they did not use their parsing bias predictively. Again, considering the high accuracy in responses to the comprehension questions, it is not likely that their parsing was incomplete. In case they did not use their parsing bias predictively during early trials, looking at the competitors could happen in the process of the cue evaluation as explained above. Associating the competitor (e.g., the motorbike) with the NP2 (e.g., *the girl*) in the given visual context would be against their world knowledge (e.g., a little girl riding the motorbike). So, they could soon conclude that this association was inappropriate, which would in turn lead their anticipatory looks to the targets rather than the competitors.

Alternatively, stronger NP2 attachment bias at the pre-test may indicate that those speakers are generally sensitive to statistical distribution of a structure in language environment. That is, their genuine sensitivity to statistical distribution could result in stronger NP2 attachment bias as NP2 attachment is more frequent in English. If it is the case, participants with stronger NP2 parsing bias could notice dominant distribution of NP2 attachment presented in a block. They may incrementally update statistical information about NP2 attachment and expect to hear NP2 attachment sentences over the course of the experiment. Accordingly, they could launch more anticipatory looks to the targets over time. This potential relationship between statistical learning ability and prediction raise questions for future research.

As for the second research question, our data did not show any evidence that individuals' parsing bias interacts with their working memory capacity and/or vocabulary size for prediction in both L1 and L2 groups. These null results seem to be mainly due to the small sample size without much variance. Given both groups of speakers were university students residing in the USA, they could be at the peak stage of cognitive and linguistic development at the time of this study. Though this study did not find any interaction effects between these factors, proficiency and working memory capacity are important factors to understand L2 language processing and learning in general, including predictive processing. Thus, how these individual difference factors interact with speakers' parsing bias for prediction should be addressed in future studies with larger samples, possibly with a wider range of age and proficiency.

Despite the novel findings, this study has some limitations. The visual world eye-tracking task only included NP2 attachment sentences, and thus it is not clear whether participants would show the mirroring pattern while processing the opposite construction, NP1 attachment. A replication study is required to examine whether the same pattern would be observed when listeners process NP1 attachment sentences (e.g., *I see the uncle of the girl that will blow the tuba* accompanied with the example visual display in Figure 1): The more biased toward NP1 attachment, the more anticipatory looks to the targets (e.g., the tuba) than to the competitors (e.g., the pin wheel) over time.

To conclude, recent research about linguistic prediction advanced our understanding of language processing and learning. In particular, the findings of linguistic prediction provided indirect support for the error-based learning account which links language processing and learning using predictive mechanisms. This account posits predictive processing is highly related to the underlying mechanisms of implicit learning, and speakers are proposed to predict based on their prior linguistic experience such as parsing bias. The current study designed to test this assumption found that the influence of parsing bias on prediction increased over time in both L1 and L2 speakers. These findings suggest that L2 speakers' prediction is guided by their linguistic experience; not only long-term linguistic experience (i.e., parsing bias) but recent experience with linguistic input also contributes to their predictive processing. Recent linguistic experience (e.g., exposure to the sentences at early experimental trials) seems to help them evaluate the use of their parsing bias as a predictive cue. The results of this study hold pedagogical implications for L2 comprehension as comprehension processing could be facilitated through prediction using individuals' parsing bias. In the L2 learning context, therefore, L2 speakers can be informed about potential predictive cues, both linguistic and non-linguistic cues, and encouraged to make use of them to generate predictions for the facilitation of their comprehension process. In terms of L2 prediction and learning, another important question remains unanswered: Whether L2 speakers learn target structures by means of prediction errors is closely related to another assumption of the error-based learning account. As answering this question is essential to understand the implicit learning mechanisms, it awaits future research.

Applicable levels: Tertiary

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