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Prediction and Error-Driven Learning

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Abstract

Prediction refers to the use of information currently available to create expectations about what will happen next. This chapter begins by illustrating effects of prediction in language comprehension and processing, as demonstrated in seminal psycholinguistic experiments with native (L1) and non-native (L2) speakers. It is now well established that both L1 and L2 speakers engage in prediction during language comprehension. Yet a generalization that has emerged from recent research is that L2 users sometimes, but not always, show reduced and/or delayed effects of prediction. To what extent this is due to reduced linguistic or cognitive *ability* to engage in predictive processing in an L2, or to the reduced *utility* of prediction to achieve successful processing outcomes in an L2, is a topic of ongoing investigation in the field. Evidence for the potentially modulating role of user-internal and -external factors, including proficiency, working memory capacity, and task demands, is reviewed. The chapter concludes with a brief discussion of prediction error as mechanism for learning, as proposed by theoretical and computational models of error-based learning in cognitive science, and the implications of such proposals for SLA, which have only just begun to be explored, raising intriguing questions and possibilities for future research in applied linguistics.

Keywords

prediction, anticipation, expectation, L2 processing, prediction error, error-based learning

Introduction

Prediction–our ability to use information currently at our disposal to make informed guesses about what will happen next–is a fundamental property of human behavior that goes far beyond language. When you look out the window and see dark clouds in the sky, you may predict that it will rain soon. You cannot predict that it will rain for sure, so your prediction is not a categorical one, but a probabilistic estimate of the likelihood of rain. Your estimate, or prediction, will be more accurate the more experience you have had with weather patterns in that area. In particular, you may have predicted wrongly in the past (and gotten wet as a result). In response to that prediction error, you would have made adjustments to your knowledge of weather patterns in that region, such that when you see the sky look similar again in the future, you will be more likely to predict that it will rain. Again, you will not be able to know for sure that it will rain, but your gradient estimate of the likelihood of rain would have shifted a bit further away from 0 and closer to 1. In other words, you would have *learned* from *prediction error*.

In this chapter, we will begin by illustrating effects of prediction in language comprehension as demonstrated in seminal psycholinguistic experiments with native (L1) and non-native (L2) speakers, and discuss how, when, and why L2 users may engage in predictive processing differently and/or to a lesser extent than native speakers. We then turn to the role of prediction in error-driven learning, and the potential contribution of this learning mechanism to (second) language acquisition (SLA).

Evidence of prediction in language processing

Prediction is involved in our use of language at multiple levels. In the field of conversation analysis, it has long been known that interlocutors try to predict, or *project*, the end of the current speaker's turn, so that they can prepare and time their own turn accordingly (see Levinson & Torreira, 2015, for review). In applied linguistics, the term *prediction* has sometimes been used to refer to *inference generation*, for example, in contexts of L2 reading where learners draw on contextual information to fill a gap in a cloze test, or figure out the meaning of a word they do not know. In the study of (L1) discourse processing, the notion of *expectancy* has been used to describe comprehenders' estimates of the likelihood that a discourse referent will be mentioned again, a construct typically measured through written story continuation tasks (Arnold, 2010). Prediction in this sense is not limited to likelihood estimates generated on a millisecond scale in real time, but encompasses a more general notion of *preparedness* for new information, the idea that our mind is not a blank slate when we deal with incoming input (Ferreira & Chantavarin, 2018).

To illustrate this broader notion of prediction, consider the beginning of the following sentence: *The boy will ride...* Without any further context, your knowledge of English will lead you to expect another noun phrase, because you know that *ride* is a transitive verb that requires an object, and more specifically a noun phrase denoting something that one can ride, such as a bicycle, a motorcycle, or a wave. While all three of these noun phrases would make for a perfectly good continuation of this sentence, you are unlikely to predict them with equal likelihood, given your knowledge of the world: Children do not typically ride motorcycles, and unless you are a surfer, you have probably experienced more situations involving boys riding bicycles than boys riding waves. Thus your previous experience and knowledge affects the *predictability* of these three (and many other possible) continuations. In research on prediction in language processing, predictability is typically quantified as a proportion (a value between 0 and

1), based on the number of people who provided that word when asked to complete sentence fragments like the one in our example.

Graded predictability values like these can then be used in experimental research that investigates what is sometimes called prediction in the narrow sense, that is, effects of prediction that can be measured in real time before the actual object of prediction is mentioned (Pickering & Gambi, 2018). In our example above, this would mean demonstrating that the listener was more likely to expect *bicycle* than *wave,* and more likely to expect both *bicycle* and *wave* than, say, *table*, after they had heard *ride* and before they heard the actual noun that followed in the speaker's utterance. This leaves a very short window of time for investigation of prediction in this narrow, strictly anticipatory sense. There are two experimental measures of real-time processing that have been the primary tools in psycholinguistics for investigating such effects: the visual world eye-tracking paradigm, a behavorial measure that takes advantage of the fact that we tend to look at images representing the meaning of what we are currently processing, and event-related potentials (ERPs), a neuroscientific measure derived from electroencephalogram (EEG) recordings of brain activity.

In a seminal ERP study investigating prediction in language processing, Wicha and colleagues (2004) had adult native speakers of Spanish read sentences that ended in a highly predictable noun, as illustrated in (1).

(1) Example item from Wicha et al. (2004)

El príncipe soñaba con tener el trono de su padre. El sabía que cuando su padre muriera podría al fin ponerse ***la corona*** *por el resto de su vida.*

('The prince dreamt about having the throne of his father. He knew that when his father died he would finally be able to wear **the [fem] crown [fem]** for the rest of his life.')

The experiment also contained items in which the critical noun was replaced with a semantically incongruous (and hence very low predicability) noun, such as *la maleta* ('the [fem] suitcase'). Results showed a so-called N400 effect when an unexpected noun was encountered: an increased negative-going voltage change around 400 milliseconds after the onset of the noun, indicating that listeners were surprised by what they heard at that point. More importantly for the measurement of prediction in the narrow sense, their experiment also included items in which the article preceding the noun was replaced with a grammatically incongruous one, such as **el corona/maleta* ('the [masc] crown/suitcase'). The critical question was whether there would be a similar effect of surprisal already at the article: If readers pre-activate, or predict, the noun *corona*, one would expect that its grammatical gender, in this case feminine, should also be preactivated. Thus when encountering the masculine article *el* in this context, the reader with that expectancy in mind should be surprised, and this surprisal should register even before the noun itself is encountered. Indeed, Wicha and colleagues found distinctly different ERP responses (albeit not N400 effects) in sentences with unexpected vs expected articles, even before the noun itself was encountered. This led to the conclusion that (native) readers must have proactively anticipated the noun, including its grammatical gender, prior to actually having seen the noun itself.

In one of the first studies on predictive processing in an L2, Foucart et al. (2014) conducted a similar ERP experiment with French L2 learners of Spanish and with Catalan-Spanish early bilinguals. Consistent with the findings from Spanish monolinguals, both of these groups showed electrophysiological effects of surprisal when they encountered an article whose gender was not consistent with the predictable noun. The authors concluded that bilinguals engage in prediction similarly to monolingual native speakers, at least when the L2 is typologically similar and prediction is based on a linguistic property that is also present in the L1.

Another early study on prediction in L2 also looked at grammatical gender but using the visual-world eye-tracking paradigm. In a series of experiments, Lew-Williams and Fernald (2010) had English-speaking L2 learners of Spanish listen to simple sentences like *Encuentra la pelota* ('Find the [fem] ball') while looking at visual scenes containing two images: the target object (ball) and a competitor object representing either a noun with the same grammatical gender (e.g., *la galleta*, 'the [fem] cookie') or a different gender (*el zapato,* 'the [masc] shoe'). The hypothesis was that if listeners use the gender information encoded on the article to anticipate, or predict, the upcoming noun, they should be faster to direct their eye gaze to the target in the different-gender condition (*la pelota, el zapato*) than in the same-gender condition (*la pelota, la galleta*). In an earlier study with native Spanish-speaking adults and 3-year-olds, Lew-Williams and Fernald had found support for this hypothesis, indicating that from an early age, native Spanish speakers use gender-marked articles to predict during real-time listening. In contrast to these findings, their adult L2 learners, including highly proficient ones in a follow-up study, showed no difference in their looking patterns between the two conditions. Interestingly, the expected difference emerged only in an experiment in which gender-marking was *semantically* informative, that is, reflective of biological sex: When hearing *Encuentra la niña* ('Find the [fem] girl'), L2 learners, like native speakers, were faster to look at the target (girl) when the competitor was masculine (e.g., *el niño*, 'the [masc] boy') than when the competitor was also feminine (*la señora*, 'the [fem] woman'). Collectively, these findings illustrate clearly that prediction is also involved in the processing of a non-native language, yet they indicate that prediction may play a more limited role in L2 than in L1 processing.

Factors modulating engagement in prediction

Based on early findings like those by Lew-Williams and Fernald suggesting that L2 users do not always engage in prediction to the same extent as native speakers, Grüter et al. (2014) proposed the generalization that L2 learners have *Reduced Ability to Generate Expectations (RAGE*; for a similar earlier proposal, see Kaan et al., 2010). The RAGE hypothesis in its strongest form–that L2 learners cannot predict at all–is clearly wrong, as demonstrated already by the early studies discussed above. Nevertheless, over the past decade, an increasing number of studies have investigated the role of prediction in L2 processing by comparing effects of prediction between L1 and L2 users, and the pattern that has emerged collectively is one whereby effects of prediction are often reduced and/or temporally delayed among L2 compared to L1 users. Importantly, it has also emerged that this is not always the case, and that a number of factors appear to be involved in whether L2 and L1 users pattern alike or not. Moreover, recent studies have also shown that engagement in prediction can vary substantially even among L1 users. In consequence, the focus of inquiry has shifted towards examining what modulates language users' engagement in prediction, both in L2 and in L1. These inquiries are very much a matter of ongoing investigation at this point, and it is beyond the scope of this chapter to provide a comprehensive review of all the factors that have been considered. We thus provide only a brief overview of potentially relevant factors here, and refer the reader to the more comprehensive recent reviews listed under Further Reading below.

The factor that is often invoked as the most obvious and intuitive potential modulator is L2 proficiency. Surprisingly, only very few studies have been able to demonstrate reliable effects of proficiency on predictive processing; and in these studies, the measures of proficiency tended to correlate strongly with measures of knowledge of the particular predictive cue involved (e.g., grammatical gender; Hopp & Lemmerth, 2018). By contrast, several recent experiments which were explicitly designed to test effects of proficiency on predictive processing, and which included independent measures of global proficiency, reported effects of prediction among L2 users, but found no evidence that these effects were modulated by global proficiency (e.g., Ito et al., 2018). Notably, some of these studies reported reliable effects of proficiency on other aspects of processing, such as the speed of information integration and revision. This indicates that the measures of proficiency included in these studies had sufficient validity to capture relevant variance in other domains, but their explanatory power did not extend to variability in the use of prediction. Like all null results, these findings must be interpreted with caution; nonetheless, they should not be ignored. Collectively, they suggest that it is not, or at least not primarily, a language user's overall proficiency, but their knowledge of the specific linguistic cues involved, and thus the likelihood of launching a *successful* prediction based on those cues, that determines their engagement in prediction.

Some studies have shown that individual-level cognitive ability in domains such as working memory and literacy can modulate how much (L1 and L2) speakers engage in prediction; yet again, these modulating effects have not emerged consistently across studies. Thus it must remain a topic for continuing investigation to what extent *ability* (as originally conceived in the *A* of the *RAGE* hypothesis), in the sense of cognitive bandwidth to accommodate prediction in addition to lexical access and incremental integration, is a critical factor in explaining variability in predictive processing. At the same time, another line of inquiry has focused on how demands of the task at hand may increase or decrease comprehenders' engagement in prediction. Findings from this still limited line of research have been quite consistent so far: When the task explicitly involves guessing upcoming words or utterances, participants are more likely to show effects of prediction in real-time processing. Conversely, when the input is manipulated such that the reliability of potential cues for prediction is reduced, comprehenders adapt quickly and refrain from predicting. These results are consistent with theoretical proposals that view prediction not as a fully automatic, unavoidable, and necessary mechanism of language processing, but as an optional, additional resource that is recruited only when it has the promise to be useful, that is, when its benefits are likely to outweigh its costs.

The trade-off between benefits and costs is central to the view of prediction as a function of *utility* (Kuperberg & Jaeger, 2016). It may also be key to understanding why we see differential engagement in prediction in different types of language users: If you have solid knowledge of a particular grammatical property (e.g., grammatical gender) and ample experience using it for prediction, you are more likely to make predictions that will actually be confirmed, and thus increase your processing efficiency. By contrast, if your knowledge of and experience with that property is more spotty, the chances of your prediction being wrong are greater. An incorrect prediction is costly in that it requires revision of what had been anticipated; it thus *decreases* processing efficiency. With this in mind, if language processing is rational in the sense of optimizing processing efficiency given the knowledge state of the system, available resources, and task goals, we should expect that there will be circumstances where *not* engaging in prediction will be the most efficient way to go. Thus, the reduced engagement in prediction that is sometimes observed among L2 users when compared to L1 speakers may, in fact, be a reflection of their optimal use of resources to maximize processing efficiency for the immediate task at hand.

In sum, rather than seeing L2 users' reduced engagement in prediction as a *failure* to achieve "native-like processing efficiency", we may view it as *successful* optimization of processing efficiency given their knowledge and resources. Yet this raises an interesting conundrum when it comes to prediction as a potential mechanism for learning, as illustrated above with our example about clouds and the chances of rain: If prediction (error) leads to learning, and L2 learners engage less in prediction to maximize immediate processing efficiency, (how) can they benefit from prediction as a learning mechanism? We will return to this question at the end of the next section.

Prediction and learning

While psycholinguists' original interest in prediction was motivated by trying to understand how prediction may facilitate language comprehension in real time, a related but originally independent strand of research in cognitive science has focused on prediction as a potential mechanism for learning. Every prediction we make about what will happen next creates an opportunity for receiving feedback, simply by observing what actually happens next, and comparing that against our original prediction. Put differently, prediction and the computation of prediction error can serve as a hypothesis testing device in the service of learning (Philipps & Ehrenhofer, 2015). When prediction and actual outcome match, this constitutes positive feedback that confirms and strengthens the current knowledge system. Conversely, when a prediction is disconfirmed, the *prediction error* can be used to revise the current system, with the goal of optimizing the system so that it will maximize correct predictions and minimize prediction errors in the future. This gradual process of *adaptation* is what constitutes *learning* in theoretical and computational models of error-based implicit learning in cognitive science (e.g., Chang et al., 2006).

The majority of research that has applied error-based learning models to language has used structural priming as an experimental paradigm to investigate adaptation and learning among adult native speakers. In a classic structural priming experiment, participants are systematically exposed to a particular grammatical structure, such as passives, and the question is whether they will increase their own production of this structure as a result of the priming treatment. Countless studies have demonstrated effects of structural priming with native speakers, as well as–though somewhat less consistently–with L2 learners (see Jackson, 2018, for review). These changes in participants' production choices, especially if they are found to persist in delayed post-tests, have been interpreted as reflecting implicit learning as a result of the computation of prediction error: participants had expected (predicted) a particular structure, e.g., an active sentence, but their prediction was repeatedly disconfirmed by the encounter of a passive sentence; this repeated encounter of prediction error led to adjustments in their system that, in turn, led them to be more likely to expect, and ultimately produce, a passive sentence themselves. Studies showing that priming effects are particularly strong when the primed structure has low frequency further support error-based learning accounts: such structures are less likely to be predicted, thus causing greater prediction error, and therefore more adaptation and learning (Jackson, 2018).

Findings such as these have led to the claim that prediction is not only beneficial for speeding up real-time processing, but may also be a mechanism for language learning. As noted above, taken together with the evidence that L2 users tend to engage in prediction less consistently, this raises an intriguing question: Does *not* predicting in order to maximize *immediate* processing efficiency prevent L2 learners from engaging in valuable opportunities to learn from prediction errors and fine-tune their knowledge systems, which in turn could lead to increasing *future* processing efficiency? At this point, the connection between prediction as a means to increase (immediate) processing efficiency and prediction as a (longer-term) learning mechanism remains poorly understood, and has only just begun to be addressed empirically in SLA (Hopp, 2021). From a more applied perspective, one way to try and bridge this gap is to create tasks that *force* learners to predict and compute prediction error. An initial, small scale study that integrated a guessing game into a structural priming task showed that learners who were forced to guess (*predict*) an interlocutor's utterance before actually encountering it (*compute prediction error*) were more likely than learners who simply repeated the interlocutor's utterance to start using the linguistic structure used by that interlocutor in their own productions (*learn*; Grüter et al., 2021). Thus a broader direction for future work could be to explore how creating tasks that encourage L2 learners to predict may support L2 learning.

Summary and future directions

It is now well established that language users, both native and non-native, engage in prediction during language comprehension. The extent to which they do so varies, depending on a number of user-internal and -external factors that are the object of much current research in psycholinguistics. A generalization that has emerged is that L2 users sometimes, but not always, show reduced and/or delayed effects of prediction. To what extent this is due to reduced (linguistic or cognitive) capacity to engage in predictive processing in an L2, or to the potentially reduced utility of prediction to achieve successful processing outcomes in an L2, remains a topic of ongoing investigation. Finally, against the backdrop of theoretical and computational models of error-based learning, the role of prediction as a potential learning mechanism in SLA has begun to be explored in laboratory-based experiments. Studies in language learning contexts beyond the laboratory, including research looking at longer-term learning outcomes, will be needed to further explore the potential implications of prediction as a mechanism for language learning within applied linguistics and language pedagogy.

See also:

wbeal1063.pub2

wbeal20356

wbeal0106.pub2

wbeal0529.pub2

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