Anticipatory and Locally Coherent Lexical Activation Varies as a Function of Language Proficiency

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Abstract

Interpreting sentences spoken in a second language can be demanding and plagued with uncertainty, especially for lower proficiency listeners. While native language listeners use numerous information sources to anticipate upcoming words accurately, the pattern of anticipation may be different for second language users. We explore this issue in bilinguals with varying English proficiency by recording anticipatory eye-movements as participants listened to sentences (e.g., "The pirate chases the ship") for which the object and three distractors (agent-related, action-related, unrelated) appeared in the concurrently presented images. Higher proficiency participants were faster than lower proficiency participants. Fixations to action-related distractors after onset of the action also varied by proficiency, with lower proficiency participants showing greater tendency to fixate this locally coherent action-related distractor. This final effect is supported by a trial level analysis, but appears to be unrelated to the effect of proficiency on anticipation speed.

Keywords: Individual differences, Language processing, SLA, Eye-tracking, Visual-world paradigm, Prediction

Introduction

It has long been accepted that the integration of newly activated lexical information plays an important role in sentence processing, but only relatively recently has the central role of anticipatory lexical activation become apparent (Altmann & Kamide, 1999; DeLong, Troyer, & Kutas, 2014; Levy, 2008). Like many cognitive processes, the ability to anticipate varies as a function of numerous individual differences, including vocabulary size (Borovsky, Elman, & Fernald, 2012; Mani & Huettig, 2012), age (Borovsky et al., 2012; Borovsky, Sweeney, Elman, & Fernald, 2014; Wlotko, Federmeier, & Kutas, 2012) and verbal fluency (DeLong, Groppe, Urbach, & Kutas, 2012; Federmeier, McLennan, De Ochoa, & Kutas, 2002). These and other related individual differences change dramatically over the course of not only native language (L1) acquisition, but also over the course of second language (L2) acquisition. Indeed, there is growing evidence that patterns of anticipatory lexical activation in sentence comprehension change as L2 proficiency develops (Chambers & Cooke, 2009; Dussias et al., 2013; Hopp, 2013; Kaan, 2014). Here we further investigate this issue by asking: How does L2 proficiency influence *the timing and dynamics* of lexical activation during spoken sentence comprehension?

We explore this question using the Visual World Paradigm (VWP; Tannenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995), in which measurements of eye fixations to a scene or set of referents, made while listening to spoken language, are taken as an index of online processing. We use an experimental design where participants listened to simple sentences of the form "The pirate chases the ship" while viewing a set of four images: the target object (SHIP), an agent-related distractor (TREASURE), an action-related distractor (CAT), and an unrelated distractor (BONE). The task is to select the image that "goes with the sentence." On the assumption that visual attention reflects referential processing, we take proportion of looks to each image as an index of the amount of lexical activation of its referent. We take an increase in looks prior to the referent being named as an indication of anticipatory lexical activation.

Returning to the question at hand, one possibility is that increased proficiency leads to faster and more robust anticipatory lexical activation. This option is supported by (child and adult) L1 findings showing that vocabulary skill affects the timing of sentential prediction. Adults as a group demonstrated faster anticipatory lexical activation than children, and participants with higher vocabularies were faster than those with lower vocabularies within their respective age groups (Borovsky et al., 2012). Differences between L1 and L2 users in speed of information integration are well known (e.g., Kilborn, 1992), yet to what extent differences in (L2) proficiency relate to speed of *anticipatory* processing has not been explored in detail.

In addition to differences in speed, we also consider the possibility that proficiency may alter the dynamics of lexical activation for referents that are *less likely* given the cumulative evidence from the unfolding sentence at a given point, but which are *locally* coherent with the most recently encountered word. In the specific setup used in our experiment, locally coherent lexical activation takes the form of increased looks to the action-related distractor after the onset of the verb (e.g., looks to CAT after hearing "The pirate *chases*"). Looks to the action-related distractor are typically seen in native language processing regardless of the fact that the action-related distractor has already been disqualified as a likely target by the agent (Borovsky et al., 2012). While this pattern may seem less than optimal, locally coherent processing may play the important role of facilitating recovery in the face of uncertainty and unexpected outcomes (McClelland & Elman, 1986). Interestingly, this type of activation at a semantic/sentential level was found to be absent in children with SLI (Borovsky, Burns, Elman, & Evans, 2013), though it appears to be boosted at a phonological level in children with SLI (McMurray, Samuelson, Lee, Tomblin, 2010). Together, these findings suggest that the timing and pattern lexical activation during sentence processing may vary according to individual differences in language proficiency and experience. Here we explore whether the degree of activation of locally coherent referents is similarly related to differences in proficiency in adult bilinguals.

Method

Participants

Sixty-eight bilingual college students (mean age: 21.6 years, 52 women), all with a first language other than English and a range English proficiency (from self-declared native speakers to second language learners who acquired English later in life) participated in return for course credit. The sample is highly heterogeneous, including simultaneous bilinguals who have multiple first languages, sequential bilinguals who learned another first language before learning English, and heritage speakers who no longer use their first language regularly. For the purpose of this study, we simply refer to the language other than English as the 1st Language, and English as the L2. Participants reported normal hearing, normal or corrected-to-normal vision, and no history of diagnosis of mental illness or treatment for speech, language or cognitive issues. One participant was excluded for receiving prior speech therapy.

Stimuli

The stimuli used in this experiment were the same as in Borovsky et al. (2012), for which eight sentence quartets were developed by mixing two agents, two actions, and four themes appropriate for each agent-action combination. All sentences consisted of the standard structure: article, agent, action, article, theme. An example quartet is:

1. The pirate hides the treasure.
2. The pirate chases the ship.
3. The dog hides the bone.
4. The dog chases the cat.

Each quartet had an associated image that consisted of photo-realistic pictures of the four themes, each presented on a 400 × 400 pixel white square background in its own quadrant of a black screen. Across the four image/sentence combinations each of the theme pictures corresponded variously to each of four conditions: target, agent-related distractor, action-related distractor, and unrelated distractor. Thus each word and image served as its own control across lists, balancing for differences in intrinsic saliency. Additionally, across all versions of the study each theme picture appeared with equal frequency in each quadrant, and in a given version the target image appeared with equal frequency in each quadrant.

The sentences were presented as auditory stimuli that were recorded by a female native English speaker (A.B.) in a child-directed voice, sampled at 44,100 Hz on a single channel. Word durations were normalized to the following values: Art1, 134 ms; agent, 768 ms; action, 626 ms; Art2, 141 ms; target, 630 ms. For a given version of the study, participants saw each of the eight images twice, each with a different associated sentence, so that any one participant heard 16 of 32 possible sentences.

Procedure

Experimental Task The stimuli were presented on a 17-inch LCD display using a PC computer running EyeLink Experiment Builder software (SR Research, Mississauga, Ontario, Canada). Participants were told they would see sets of pictures while listening to sentences, and that they should click on the picture that "goes with the sentence." Before the experiment, the eye-tracker was focused and calibrated using a manual 5-point calibration and validation with a standard black-and-white 20-point bull's-eye image. Before each trial, participants were presented the same bull's eye in the center of the screen, with the trial starting once they had fixated on it. The images were presented for 2000 ms before sentence onset, and remained on the screen after sentence offset until participants clicked on an image with the mouse.

Eye Movement Recording Eye movements were sampled at 500 Hz using an EyeLink 2000 remote eye-tracker attached directly below the LCD display. A remote arm configuration allowed for flexible adjustment of the camera and display so as to allow for reliable positioning within 580-620 mm from the participant's (typically right) eye. Head and eye-movement were automatically tracked by the system via a sticker affixed to each participant's forehead.

For each trial, eye-movements were recorded from image onset until participants clicked on a picture with the mouse. The eye-tracking system automatically classified recorded eye-movements into saccades, fixations and blinks using default settings, and were then binned into 10 ms intervals for subsequent analyses.

Offline Measurements Prior to the eye-tracking task participants completed a language history questionnaire. After the eye-tracking task they were administered two offline language measures: the Peabody Picture Vocabulary Test-Version 4 (PPVT; Dunn & Dunn, 2007) and the

Sentence Completion subtest of the Comprehensive Assessment of Spoken Language (CASL-SC; Carrow-Woolfolk, 1999).

Assignment to Proficiency Groups Placement in a given Proficiency Group was determined by participants' answers to the question: "Do you consider yourself a native speaker of English?" Participants who answered "yes" were put in the Higher Proficiency group (n=32), whereas participants who said "no" were put in the Lower Proficiency group (n=35). While this criterion for group assignment is a relatively crude one, comparisons between the two subgroups for various offline measures of language ability support this grouping. The mean values for participants' scores on the PPVT (age-normed), CASL-SC (age-normed), and five answers from the language history questionnaire, by Proficiency Group, are shown in Table 1. Proficiency in English and 1st language was measured by self-ratings on a scale from 1 to 10. With the exception of age, $t(57.21) = -.74$, $p = .46$, $d = .20$, there were significant group differences for all other measures (comparisons assume unequal variances): PPVT, $t(53.75) = 4.19$, $p < .005$, $d = 1.14$; CASL-SC, $t(48.78) = 2.37$, $p < .05$, $d = .68$; English proficiency, $t(57.97) = 3.88$, $p < .005$, $d = 1.02$; English Age of Acquisition (AoA), $t(62.05) = -6.16$, $p < .005$, $d = 1.56$; English experience, $t(49.53) = 5.33$, $p < .005$, $d = 1.51$; 1st language proficiency, $t(62.52) = -4.47$, $p < .005$, $d = 1.13$.

Overall, the results of the offline measures and questionnaire answers support the groupings, painting a picture in which participants in the Lower Proficiency group are significantly different from the self-declared native speakers in the Higher Proficiency group. Using these groupings we are able to plot the time course of proportions of fixations to the target and distractors across trials and highlight group level differences, which we then explore further using a continuous measure of proficiency.

Table 1: Mean values of offline measures and questionnaire answers by Proficiency Group

Proficiency Group	Higher Prof. n = 32	Lower Prof. n = 35
PPVT	100.90	90.17 **
age-normed	(11.81)	(8.47)
CASL-SC	96.17	89.15 *
age-normed	(13.43)	(9.25)
Eng. Prof.	9.42	8.51 **
self-rating	(0.72)	(1.15)
AoA (yrs)	2.47	7.43 **
	(2.77)	(3.75)
Age (yrs)	21.35	21.74
	(1.58)	(2.59)
Eng. Exp. (yrs)	19.42	13.03 **
	(2.98)	(6.35)
1st Lang. Prof.	6.91	8.50 **
self-rating	(1.51)	(1.38)

Note. Standard deviations are reported in parentheses.
* $p < .05$. ** $p < .005$.

Results

Behavioral Accuracy

The accuracy with which participants selected the correct target picture in the experimental task was checked in order to make certain that they understood the sentences and the task. Accuracy was high, with only 8 incorrect responses (99.3% correct).

Eye-movement Analyses

Time Course by Proficiency Group: To explore anticipatory and locally coherent eye-movements during the incremental processing of the sentences, the timecourse of fixations was visualized by first calculating the mean proportion of time spent fixating the four target areas in each image (the target, agent-related, action-related, and unrelated pictures). These means were then averaged across participants in each of two Proficiency Groups and plotted against time from sentence onset in Figure 1.

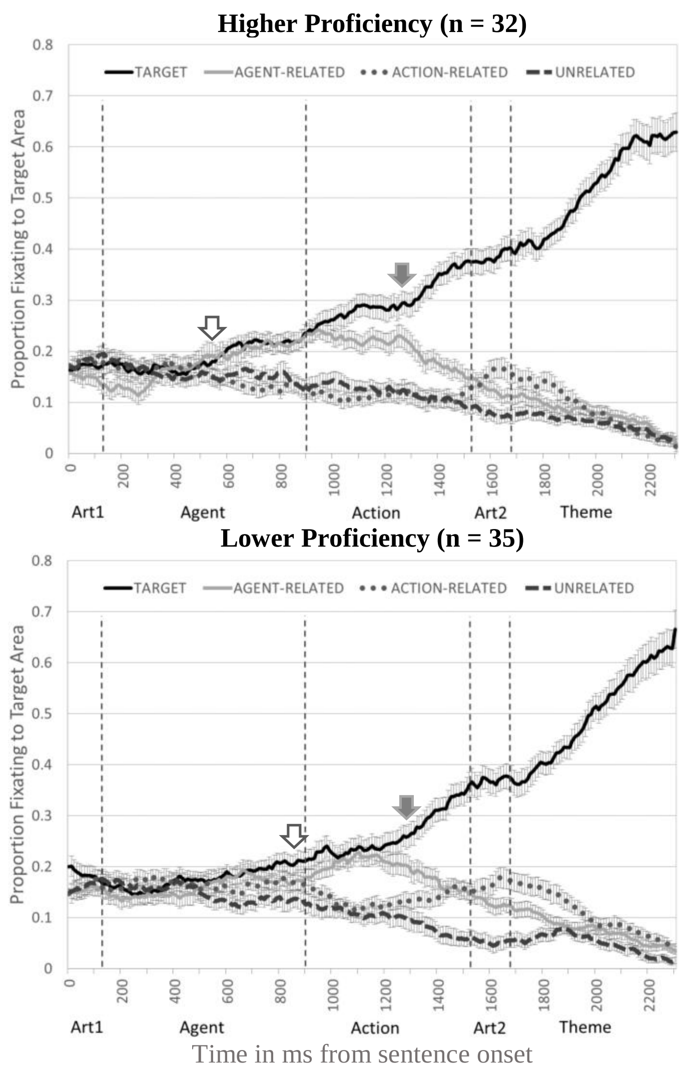

Figure 1: Timecourse of fixations to each area of interest, in 10-ms time bins (with SE bars).

In these time course plots, there are two very apparent visual patterns. First, there is a rapid rise in fixations to the target that continues to the end of the trial. This rise appears to begin near the border between the agent and action time windows for both groups, and is initially accompanied by an equal increase in fixations to the agent-related distractor. Second, there is a momentary increase in fixations to the action-related distractor. This begins near the end of the action time window and subsides in the theme time window.

We then carried out analyses that address two main issues, (1) does the timing of anticipatory fixations vary between high and low proficiency groups and (2) do patterns of fixations to the locally coherent referent vary as a function of proficiency?

Analysis of Anticipatory Fixations There are two places in the sentences where anticipatory lexical activation seems to occur: (1) anticipation of the theme and agent-related distractor after onset of the agent, which takes the form of a divergence in the timecourse between both agent-related (theme and agent-related) and both non-agent-related (action-related and unrelated) target areas (white arrows in Fig. 1)., and (2) anticipation of the theme after onset of the action, which takes the form of a divergence in the timecourse between the theme and the agent-related target areas (grey arrows in Fig.1). Following the methodology of Borovsky et al. (2012), significant divergence is determined as the time point at which the relevant comparisons, conducted using point-by-point one-tailed *t* tests, are significant for a minimum of five subsequent and consecutive 10-ms bins. This minimizes the likelihood of spurious results that might arise from a single pointwise comparison.[1]

For (1), comparisons were made between measures in which both agent-related and both unrelated target areas are collapsed, thus allowing for a single comparison to be made. Significant divergence occurs at 540 ms, $t(62) = 2.09$, $p < .05$, $d = .53$, for the Higher Proficiency group and at two points for the Lower Proficiency group, first ranging from 600 ms, $t(68) = 2.22$, $p < .05$, $d = .54$ to 720 ms, $t(68) = 2.28$, $p < .05$, $d = .55$, and again at 860 ms, $t(68) = 2.12$, $p < .05$, $d = .57$. For (2), significant divergence occurs at two points for the Higher Proficiency group, first ranging from 1080 ms, $t(30) = 2.2$, $p < .05$, $d = .79$ to 1230 ms, $t(30) = 2.23$, $p < .05$, $d = .8$, and again at 1260 ms[2], $t(30) = 2.21$, $p < .05$, $d = .79$, while for the Lower Proficiency group it occurs at 1290 ms, $t(33) = 2.14$, $p < .05$, $d = .73$. Although these descriptive statistics are suggestive of timing differences between the groups, our inferential statistics are not robust enough to allow for stronger claims.

Analysis of Locally Coherent Fixations Consistent with prior work in native English speakers, we see locally coherent lexical activation for Higher and Lower proficiency groups following the onset of the action. This pattern is characterized by increased looks to the action-related target area relative to the unrelated target area. Although this technically can also be considered anticipatory processing, it differs from the other instances of anticipatory processing in that it is not cumulative, ignoring what came earlier in the sentence, and resulting solely from information encoded in the action.

The increase in looks to the action-related target area is clearly visible in the timecourse plots for both Proficiency Groups, but is noticeably larger for the Lower Proficiency group than the Higher Proficiency group. In order to compare groups, we calculated the log-gaze probability ratio of percentages of looks to the action-related vs unrelated distractors in the time window going from action onset to theme onset following the methodology of Borovsky et al. (2014)), so that:

$$\text{Log-gaze} = \log\left(\frac{P(looks\ to\ action\text{-}related)}{P(looks\ to\ unrelated)}\right) \qquad (1)^3$$

With the log-gaze measure, as with normal proportions, a score of zero indicates no bias, whereas a positive score indicates a bias to look at the action-related distractor. The mean log-gaze ratio for the Higher Proficiency participants was .08 (SD = .95), and for the Lower Proficiency participants was .65 (SD = .55). Based on a comparison assuming unequal variances the groups were significantly different, $t(48.85) = -2.95$, $p < .005$, $d = .84$.

Exploring the Individual Measures that Contribute to Proficiency Effects The grouping factor of self-determined English native-speaker status could conceivably be driven by any of the measures presented in Table 1, so it would be useful to understand which factors are most important. Is it overall years of experience? AoA? Vocabulary skill? Some combination? Knowing the answer to this question would give us theoretical insight into what drives the differences in locally coherent processing. To answer these questions, we next carried out stepwise multiple regressions to determine which of the measures presented in Table 1 predict the log-gaze probability ratio for any given individual participant. Forward selection and backwards deletion methods (both using a minimum Bayesian Information Criterion stopping rule) converged on a simple regression model containing only the age-normed PPVT score (grand mean centered). To the simple model we added subjects as a random effect, r, and ran the following mixed model:

$$\text{Log-gaze}_i = \beta_0 + \beta_1 * \text{PPVT}_i + r_i \qquad (2)$$

This resulted in $\beta_0 = 0.411$, $t(63) = 4.46$, $p < .001$, $\beta_1 = -.022$, $t(63) = -2.70$, $p = .009$, with Pearson's r = .32. Thus,

[1] In the cases in which significant divergence as defined here happens twice, only the second is marked by an arrow in Figure 1.

[2] This later time is more in line with what is seen in monolingual adult native speakers (Borovsky et al., 2012).

[3] Log ratios are undefined for 0, so every 0 in either the numerator or denominator was replaced with 0.01.

out of the measures presented in Table 1, it seems that vocabulary, as measured by the PPVT, plays the most important role in driving the individual differences in the probability of fixations to the locally coherent referent.

Exploring Proficiency Effects at the Trial Level The subject level findings suggest that delayed anticipation in lower proficiency participants has cascading effects on subsequent lexical activation, which are revealed by the proficiency related differences in mean probability of fixations to the locally coherent referent. In other words, slower anticipation of the theme in lower proficiency participants appears to result in greater locally coherent lexical activation. If these findings are connected, one might expect trial level relationships between fixations towards the action-related distractor and the timing of anticipatory eye-movements to the target item. We explore this potential connection using Hierarchical Linear Modeling (HLM; Bryk & Raudenbush, 1992).

First, it is important to note that, as with the subject level log-gaze ratios, every 0 value for proportion of looks in the time window going from action onset to theme onset in either the numerator or denominator was replaced with 0.01 when calculating the trial level log-gaze ratios. However, unlike with the subject level values where mean proportions across trials were rarely equal to 0, a large number of 0's needed to be replaced when calculating the trial level values. As a result, this process added far more noise to the data in comparison to the subject level ratios and resulted in an across the board reduction in values. The mean log-gaze ratio calculated across all trials using the updated values was .03 (SD = 1.05) for Higher Proficiency participants and .24 (SD = 1.05) for Lower Proficiency participants. Given the large difference between the original mean values and those calculated after replacing the 0s, we first ran a trial level version of equation (2) with a new trial level random effect, e, as a check on the viability of the trial level log-gaze probability ratio.

$$\text{Log-gaze}_{ti} = \beta_{00} + \beta_{01}\text{* PPVT}_i + r_{0i} + e_{ti} \quad (3)$$

This resulted in $\beta_{00} = 0.145$, $t(63) = 4.09$, $p < .001$, and $\beta_{01} = -.009$, $t(63) = -3.298$, $p = .002$. Although the coefficients are smaller than in equation (2), the direction and size of the PPVT effect is nearly equivalent. Thus, even with the added noise, it appears that trial level log-gaze values appear to act in a similar manner as the subject level values.

In order to explore the hypothesis that anticipation speed and log-gaze probability ratio are related, the next step was to add the trial level time of the launch of the first saccade (1st Sac) that landed on and resulted in a fixation of the target in the anticipatory time window going from action onset to theme onset to equation (3). Z scores were used to standardize PPVT and first saccade time effect scales to allow for comparison of the coefficients.

$$\text{Log-gaze}_{ti} = \beta_{00} + \beta_{01}\text{* PPVT}_i + \beta_{10}\text{* 1}^{st}\text{ Sac}_{ti} + r_{0i} + e_{ti} \quad (4)$$

This resulted in $\beta_{00} = 0.122$, $t(63) = 2.291$, $p = .025$, $\beta_{01} = -.152$, $t(63) = -2.907$, $p = .005$, and $\beta_{10} = -.200$, $t(63) = -3.705$, $p < .001$.[4] Interestingly, while there is indeed a significant effect of 1st saccade time on the log-gaze probability ratio, it is in the opposite direction of what was expected based on the subject level proficiency related results. Instead, the effect seems to indicate that in trials where participants were slower to view the target item they were also less likely to view the action related distractor. While this result does not necessarily rule out a relationship between the two proficiency related results, it does indicate that at the trial level this specific measure of target anticipation is connected to fixations to the action-related distractor via an effect that is unrelated to the subject level proficiency effects.

Discussion

In this study we set out to address the question: How does L2 proficiency influence *the timing and dynamics* of lexical activation during spoken sentence comprehension?

The first prediction was that more proficient participants would show patterns of fixations indexing anticipatory lexical activation occurring sooner and to a greater degree than participants with lower proficiency. Although our inferential statistics are not strong enough to allow more robust claims, the descriptive results of the analysis of anticipatory fixations largely support this prediction, with the points of significant divergence between the relevant targets occurring sooner for more proficient participants.

An additional prediction was that proficiency may alter the dynamics of lexical activation for less-likely, locally coherent options across the sentence. Again, the results of the analysis of locally coherent fixations largely support this prediction, with the lower proficiency group showing a significantly greater bias to look at the action-related distractor. In other words, participants with lower proficiency, who may experience considerable uncertainty in everyday language interpretation, appear to adaptively activate less-likely locally coherent referents.

The effect of proficiency on locally coherent lexical activation holds not only at the subject level, but also at the trial level. However, the picture is complicated by a trial level effect of anticipation speed in which later anticipation of the target actually results in less activation of the locally coherent referent. While this effect indicates that there is indeed a relationship between speed of anticipation and the later dynamics of lexical activation, it is in the opposite direction of what would be expected based on the subject level proficiency results, namely that slower anticipation of the theme would result in greater locally coherent lexical activation.

[4] A subject level random effect for 1st Saccade was not included based on the result of a deviance test

Overall, the results seem to weigh in favor of the interpretation that two separate effects of proficiency on lexical activation are at play in the comprehension of simple sentences of the kind used in this experiment, with a separate relationship between anticipation speed and the degree of locally coherent lexical activation also playing an important role.

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