Selective Attention Based on Speech Complexity and Learning Rate

Ruthe Foushee^{a,b,1}, Mahesh Srinivasan^b, and Fei Xu^b

^aDepartment of Psychology, The University of Chicago, 5848 S. University Ave, Chicago, IL 60637; ^bDepartment of Psychology, University of California, Berkeley, 2121 Berkeley Way West, Berkeley, CA 94720

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Children are thought to learn best from information that is appropriate for them, given their current level of competence. But what role might learners themselves play in actively selecting and attending to such information? We introduce a novel method to investigate whether children's attention to *spoken language* is responsive to its complexity or appropriateness. Preschoolers (4–6 years, $M=4.6$) watched a video where a distracting animation accompanied the illustrations of a storybook. The audio narration for each page of the storybook was looped such that the story progressed faster if the child looked at the distractor for an extended period of time, indicating their loss of attention towards the story. We manipulated the complexity of the narration in two between-subjects conditions: the Simple narration contained largely familiar words, while the Complex narration contained many words typically acquired later. Children's learning was measured via post-tests of their plot comprehension and unfamiliar word knowledge. Children hearing the Complex speech were less likely to listen past the minimum duration of each page, and showed decreased gaze to the story illustrations. Across complexity levels and controlling for age, children's selective attention to the speech was significantly related to their plot knowledge. In the Complex condition — where children heard the unfamiliar words we tested in the story narration — children's attention also predicted their word learning accuracy. Our results provide evidence that young children may actively direct their attention toward linguistic input that is most appropriate for their current level of cognitive and linguistic development, which may provide the best learning opportunities.

Selective attention | Lexical development | Self-directed learning | Cognitive development | Language processing | Rational learning

A classic idea in developmental psychology holds that the complexity of a stimulus relative to what a child already knows determines its utility for learning. Child learners are surrounded by an enormous range of potential learning opportunities day-to-day, which vary in their complexity (1, 2). Here, we investigated the role that children's selective attention may play in determining the sources of information from which children will actually learn. We designed a novel method to test the hypothesis that children's attention allocation to an information source is an index of its support for their learning (3, 4). In contrast to previous research with infants, which manipulated the learnability of highly simplified visual or auditory stimuli (3, 5, 6), we used naturalistic language stimuli, which both interests children and carries real information for learning. We manipulated speech complexity via the estimated ages of acquisition of the words constituting samples of speech: more complex speech samples contained more words that are typically acquired later and may be more difficult to process (7). We further expected that children's relative familiarity with later-acquired words — and their ability to infer the

meanings of entirely unfamiliar words — would track with linguistic experience, such that more complex speech should become increasingly appropriate for children as they aged. If children's attention is influenced by such learnability considerations, we should see (1) differences in child attention to speech at different levels of complexity, (2) increases in child attention to more complex speech with age, and (3) a positive relation between a child's sustained attention to the speech, and measures of the amount they learned from the speech.

In our study, children heard a Simple or Complex narration of a textless storybook (8) while their visual attention to a display was captured via an eyetracker. On each page of the story, the illustration corresponding to the audio narration competed for children's visual attention with a continuously animated distractor (Figure 1). We reasoned that the presence of the distractor meant that children's visual attention to the comparatively dull illustration was likely to be a meaningful index of their attention to the speech. That is, we expected that children would continue to look at the illustration only as long as they were actively processing the story narration — indeed, that it would be difficult for them *not* to (9, 10) — after which they might be lured away. We made children's ongoing exposure to the speech contingent on their allocation of visual attention, such that children who were drawn in by the distractor moved through the story quickly and heard the narration for each page only once. In contrast, children whose increased gaze to the illustration suggested that they were paying attention to the speech could hear each page of the story repeated for up to five times (inset Figure 1). In this way, all children heard the entirety of the story content, but varied in whether they continued listening to further, optional repetitions of the narration for each page, as well as in their visual attention to the image that the story made salient, versus to the irrelevant distractor. Finally, to enable links between individual children's attention to the speech and their ability to learn from it, we measured children's knowledge of story content and of unfamiliar words from the story.

Materials and Methods

Participants. Forty-six English-speaking children (17 female, 4.0–6.0 years; $M=4.6$, $SD=0.47$) participated. Children were recruited from local preschools, or from a database of interested families maintained by the University of California, Berkeley. Prior to their study session, children were randomly assigned to the Simple ($n=24$, 10 female; $M=4.6$, $SD=0.54$) or Complex

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¹To whom correspondence should be addressed. E-mail: foushee@uchicago.edu

Fig. 1. Schematic of Experimental Eyetracking Procedure Manipulating the Speech Complexity of a Narrated Storybook and Measuring Child Attention and Learning.

($n=22$, 7 female; $M=4.6$, $SD=0.41$) conditions. Two additional children were excluded after another child (1) or teacher (1) intervened on their study session.

Full documentation of our procedures is at https://osf.io/zsfjb/?view_only=7ae1b045dd774d4db618c2b8735ac148.

Procedure. Children sat before a laptop and SMI RED-n eyetracker. The first screen of the experiment displayed a black-and-white animation of three penguins jumping rope (the DISTRACTOR) on the left side of the screen. Next, the cover of the book appeared alongside the DISTRACTOR, followed by six pages narrated at either the Simple or Complex level (Figure 1), each initiated by a gaze-contingent fixation cross.

Simple and Complex narrations were matched on multiple linguistic dimensions, including syllable count, speechrate, and type-token ratio, but differed in the estimated age of acquisition (AoA) of the words they used (7). The Simple narration exclusively used words from the MacArthur-Bates Communicative Development Inventory (11), while each page of the Complex narration included five word types with AoAs ~7–13 years and two tokens of a single unfamiliar word type with an estimated AoA >13 years. On each page, children obligatorily heard the narration for the page at least once (~15s), after which the same audio continued to loop for up to five additional repetitions (~75s). Children could advance the page early by switching to look at the DISTRACTOR, programmed as a 1.5s ‘trigger’ region on the eyetracker.

After the story, we measured learning via two experimenter-controlled blocks of six test trials each. Listening comprehension trials tested children’s knowledge of story events or characters, while word-learning trials asked participants to generalize the meanings of the unfamiliar target words introduced in the Complex speech to novel stimuli (e.g., from the frog ‘absconding’ from the jar to a man running away).

Areas of Interest (AOIs). We defined two equal-sized AOIs: the ILLUSTRATION (right on-screen image; Figure 1) and the DISTRACTOR (left on-screen image). We analyzed two metrics of children’s visual attention to the AOIs by page (12 values/child), and across the story (2 values/child).

Net gaze duration reflects the total time during which a child’s gaze was detectable by the eyetracker and was fixated

on a given AOI. Thus, the measure combines information about the length of the child’s exposure to the story and the distribution of their attention during it. To obtain summary values for each child, we sum net gaze durations to each AOI across pages. Duration values in models are log-transformed.

Percent gaze duration represents a child’s gaze to each AOI as a percentage of their gaze across the entire display, thereby isolating the relative distribution of their visual attention to the ILLUSTRATION versus DISTRACTOR. For single measures by child, we use the mean of children’s values for each AOI.

Results

Speech Complexity and Attention. If our manipulation of speech complexity were effective, we expected children to exhibit greater attention to the Simple speech than to the Complex speech, and to show increasing evidence of attention to the Complex speech with age.

Table 1. AOI Attention by Speech Complexity

		SIMPLE		COMPLEX	
		<i>Mdn</i>	<i>95% CI</i>	<i>Mdn</i>	<i>95% CI</i>
By Page	Net Gaze Duration (s)				
	ILLUSTRATION	14.76	(11.97, 20.83)	12.66	(7.84, 17.72)
	DISTRACTOR	5.42	(3.74, 8.28)	5.64	(3.19, 8.80)
	Percent Gaze (%)				
By Participant	ILLUSTRATION	50.5	(40.8, 64.2)	44.4	(26.9, 61.1)
	DISTRACTOR	27.9	(17.2, 50.6)	37.0	(21.4, 53.8)
	Total Gaze Duration (s)				
	ILLUSTRATION	98.00	(82.60, 117.60)	80.2	(56.50, 92.70)
	DISTRACTOR	41.4	(29.9, 44.7)	39.7	(27.2, 49.5)
	Mean Percent Gaze (%)				
	ILLUSTRATION	50.2	(45.2, 56.9)	41.8	(34.4, 57.5)
	DISTRACTOR	30.5	(23.7, 42.7)	37.0	(31.9, 47.0)

Decision to Continue Listening. To test the potential interaction between children’s age and our speech complexity manipulation, we first analyzed children’s attention in terms of whether or not they continued listening past the obligatory first repetition of each page. A mixed effects logit model (12, see *S1 Text*

Fig. 2. Model-estimated probabilities of a child listening to further optional repetitions of a storybook page narration. Child age (x-axis) was associated with a significant decrease in the probability of continuing listening in the Simple condition (OR=0.56 [0.32, 0.93]), but a significant increase in the Complex condition (OR=3.40 [1.42, 9.23]). Shaded region indicates SE.

for details) showed a significant interaction between condition and age ($\chi^2(1) = 7.37, p = .007$; Figure 2), as we would expect if children's continued listening to the speech was partly a reflection of its continued support for their learning.

AOI Gaze Duration. For a continuous index of children's attention to the speech, we fit a linear mixed effects model to children's looking times (in *log ms*) to our Areas of Interest (AOIs). While children in both conditions tended to look longer at the ILLUSTRATION than the DISTRACTOR (AOI $\beta = 0.99$ [0.86, 1.12], $\chi^2(1) = 312.68, p < .001$), their preference was weaker in the Complex condition (AOI:Condition $\beta = -0.28$ [-0.47, -0.09], $\chi^2(1) = 8.39, p = .004$), where gaze to the ILLUSTRATION was also selectively associated with age (AOI:Condition:Age $\beta = 0.25$ [0.05, 0.45], $\chi^2(1) = 6.21, p = .012$).

Attention and Learning. If children's attention to the speech was driven at least in part by their ongoing learning from it, we should see a correspondence *across conditions* between individual children's measures of attention and of learning.

Listening Comprehension. We fit linear models to children's story comprehension accuracy (% correct) for two continuous indices of children's attention to the speech (Table 2; *S1 Text*). Children's looking times to the ILLUSTRATION were significantly related to their listening comprehension scores, controlling for condition and age (Model 1: *net gaze duration* $\beta = 23.18$ [5.15, 41.20], $F(1) = 6.73, p = .012$; Model 2: *percent gaze duration* $\beta = 0.53$ [0.28, 1.34], $F(1) = 4.54, p = .039$).

Word Knowledge. Finally, we fit models to children's word-learning performance (% correct) in the Complex condition, where the unfamiliar words that we tested were used in the narration. Holding child age constant, both metrics of children's attention to the ILLUSTRATION were significantly related to test accuracy (Table 2, Model 3: *net gaze duration* $\beta = 26.20$ [4.22, 48.20], $F(1) = 5.46, p = .031$; Model 4: *percent gaze duration* $\beta = 0.81$ [0.28, 1.34], $F(1) = 8.91, p = .008$).

Discussion

Systematic differences in child attention to the Simple versus Complex speech suggest that our experimental manipulation

Table 2. Linear Models Linking Attention and Learning

	Listening Comprehension		Word Learning	
	(1)	(2)	(3)	(4)
Intercept	-195.78 (-403.13, 11.5)	43.83** (17.03, 70.64)	-71.98 (-173.54, 29.59)	5.51 (-20.60, 31.62)
Age	11.12*** (4.83, 17.40)	10.83** (4.41, 17.26)	-1.15 (-11.95, 9.64)	-3.28 (-13.52, 6.97)
Condition:COMPLEX	-0.62 (-13.92, 12.70)	-2.62 (-15.92, 10.68)	-	-
ILLUSTRATION Attention Metric				
Gaze (<i>log ms</i>) [†]	23.18* (5.15, 41.20)	0.53* (0.03, 1.03)	26.20* (2.64, 49.77)	0.81** (0.28, 1.38)
R2	0.317	0.285	0.233	0.331
Adj. R2	0.268	0.234	0.148	0.257
F	(3, 42) 6.50**	5.58**	(2, 18) 2.73	4.46**

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

[†] Participant total duration across pages

* Participant mean across pages

of speech complexity was effective, and that our novel method left children free to direct their attention between a speech stream offering new opportunities for learning and an alluring distractor. Children listening to the Complex speech were less likely to continue listening on each page, and spent less time looking at the speech-relevant visual stimulus. These effects interacted with age, such that children showed greater signs of attention to the Complex speech with age.

Our study additionally enabled us to directly test the link between children's selective attention and their learning. Previous infant research measuring attention based on complexity or learnability has necessarily employed highly simplified stimuli, with limited potential for assessing learning (3, 5, 6). Furthermore, relative to studies of infant language development, the idea that low-level processes of attention to spoken language might continue to mediate language development into the preschool years has received little attention (13). Our results offer a novel contribution to these literatures, revealing that individual children's self-directed attention to the speech in our study critically predicted their content and word learning.

Finally, we were particularly interested in children's sensitivity to naturalistic speech complexity as a means of explaining why certain sources of language input have proven to be more useful for children's learning than others. We hypothesized a critical role of attention, such that simpler, more developmentally appropriate spoken language inputs might more effectively elicit and maintain children's attention. As in other domains where, for example, children track the past accuracy of informants and use it to select who they want as a teacher (14), our results indicate that children may track the relative difficulty of processing and encoding different sources of linguistic information, and preferentially attend to those sources where their learning will be the most efficient.

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