₁ Parents fine-tune their speech to children's vocabulary knowledge

₂ XXXXX[1], XXXXX[1], & XXXXX[1,2]

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₄ [2] XXXXX

₅ Author Note

₇ Correspondence concerning this article should be addressed to XXXXX, XXXXX.

₈ E-mail: XXXXX

Abstract

Young children learn language at an incredible rate. While children come prepared with powerful statistical learning mechanisms, the statistics they encounter are also prepared for them: Children learn from caregivers motivated to communicate with them. How precisely do parents tune their speech to their children's individual language knowledge? To answer this question, we asked parent-child pairs (n=41) to play a reference game in which the parent's goal was to guide their child to select a target animal from a set of three. Parents fine-tuned their referring expressions to their children's knowledge at the lexical level, producing more informative references for animals they thought their children did not know. Further, parents learned about their children's knowledge over the course of the game, and tuned their referring expressions accordingly. Child-directed speech may thus support children's learning not because it is uniformly simplified, but because it is tuned to individual children's language development.

Statement of Relevance

The pace at which children learn language is one of the most impressive feats of early cognitive development. One possible explanation for this rapid pace is that the language caregivers produce is tuned to children's developing linguistic knowledge, maintaining just the right level of complexity to support rapid learning. We present the first experimental evidence of just how precise this tuning is, showing that parents tune not just to children's holistic language development, but their knowledge of individual words. We developed a new method in which we experimentally controlled what parents talked about, but not how they could talk or what they could say, increasing the chance that these results will generalize outside the lab. This work points to the importance of studying the parent-child dyad as a unit instead of focusing on children as isolated learners, both in the domain of language and in social learning more broadly.

35   Word count: 749

₃₆   Parents fine-tune their speech to children's vocabulary knowledge

₃₇   In just a few short years, children master their native language. Undoubtedly, a large

₃₈ share of the credit for this feat is due to powerful learning mechanisms that children bring to

₃₉ their input (Kuhl, 2004; Saffran, Aslin, & Newport, 1996; Smith, Suanda, & Yu, 2014).

₄₀ However, a share of the credit may also be due to the structure of linguistic input itself:

₄₁ individual differences in both the quantity and quality of the language children hear are

₄₂ associated with individual differences in those children's language learning (Hart & Risley,

₄₃ 1995; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Rowe, 2012). Further,

₄₄ associations between input and uptake are primarily driven by differences in speech directed

₄₅ to children. Differences in overheard speech do not predict differences in language learning,

₄₆ even in communities where child-directed speech is relatively rare (Romeo et al., 2018;

₄₇ Shneidman & Goldin-Meadow, 2012; Weisleder & Fernald, 2013). Why is child-directed

₄₈ speech so important to language learning?

₄₉   The way we speak to children is markedly different from the way we speak to adults.

₅₀ For instance, child-directed speech tends to be slower, higher pitched, and exaggerated in

₅₁ enunciation relative to adult-directed speech (Cooper & Aslin, 1990; Grieser & Kuhl, 1988).

₅₂ Beyond acoustic and prosodic differences, child-directed speech is also marked by repetition,

₅₃ simpler syntactic structures, and higher proportions of questions (Fernald & Simon, 1984;

₅₄ Newport, Gleitman, & Gleitman, 1977; Snow, 1972). Children preferentially listen to

₅₅ child-directed speech over adult-directed speech (Cooper & Aslin, 1990, p.

₅₆ @consortium2020), and their increased attention to child-directed speech may play a part in

₅₇ driving language acquisition (Soderstrom, 2007).

₅₈   In addition to attentional effects, structural simplifications in child-directed speech

₅₉ have been tied to specific benefits in children's language learning (e.g. Brent & Siskind, 2001;

₆₀ Ma, Golinkoff, Houston, & Hirsh-Pasek, 2011). For instance, when parents refer to a

₆₁ particular object, they tend to place this object in the final position of their utterances, even

62 in languages where this is not the canonical word order (Aslin, Woodward, LaMendola, &

63 Bever, 1996). This structural tendency has been tied directly to ease of word segmentation

64 and subsequent word learning (Endress, Nespor, & Mehler, 2009; Yurovsky, Yu, & Smith,

65 2012).

66   Crucially, both acoustic and structural properties of child-directed speech change over

67 development, with sentences getting longer, more complex, and less acoustically variable

68 (e.g. Huttenlocher et al., 2010; Liu, Tsao, & Kuhl, 2009; Phillips, 1973). The linguistic

69 tuning hypothesis suggests that this changing nature of child-directed speech is what allows

70 it to be such a powerful driver of language development (Snow, 1972). If parents tune their

71 speech to children's developmental level, increasing the complexity of input at the same rate

72 that children are developing their linguistic knowledge, input may always be at the optimal

73 level of complexity to support language learning (Vygotsky, 1978).

74   How precisely do parents tune their speech? One possibility is that tuning is *coarse*:

75 Caregivers could tune the complexity of their speech generally, using a holistic sense of their

76 children's developing linguistic abilities. Consistent with a coarse-tuning hypothesis, parents

77 tune their utterance lengths, articulation of vowels, and diversity of clauses to children age

78 (Bernstein Ratner, 1984; Huttenlocher et al., 2010; Moerk, 1976). Over and above this

79 coarse-tuning, parents might *fine-tune* their speech, taking into account not only children's

80 global linguistic development, but their specific knowledge of smaller units of language, such

81 as lexical items. Fine-tuning would provide a particularly powerful and efficient vehicle for

82 scaffolding language acquisition because of its specificity. If parents could fine-tune

83 utterances containing specific words, phrases, or constructions, they could keep each aspect

84 of language at just the right desirable difficulty to support learning, retention, and

85 generalization (Bjork & Kroll, 2015; Vlach & Sandhofer, 2014).

86   To date, the only evidence for fine-tuning comes from two observational studies, one

87 showing that parents are more likely to provide their child with labels for novel as compared

88 to familiar toys (Masur, 1997), and the second showing that one child's caregivers produce

89 their shortest utterances containing a particular word just before the child first produces

90 that word (Roy, Frank, & Roy, 2009). Here, we present the first *experimental* evidence for

91 fine-tuning.

92   Children and their parents played a reference game in which the parent's goal was to

93 guide their child to select a target animal from a set of three. Parents tuned the amount of

94 information in their utterances not just to the average difficulty of each animal word, but to

95 their prior estimates of their individual child's knowledge of that animal. Further, parents

96 sensitively adapted over the course of the game, providing more information on subsequent

97 trials when they discovered that their child did not know an animal. Together, these results

98 show that parents leverage their knowledge of their children's language development to

99 fine-tune the linguistic information they provide.

Method

Participants

102   Toddlers (aged 2-2.5 years) and their parents were recruited from a database of families

103 in the local community or approached on the floor of a local science museum in order to

104 achieve a planned sample of 40 parent-child dyads. Because our method was novel, we chose

105 a sample size that would give us 95% power to detect a medium-sized effect (d=.6)

106 within-subjects and rounded up to the nearest multiple of 10. A total of 48 parent-child

107 pairs were recruited, but data from 7 pairs were dropped from analysis because of failure to

108 complete the experiment as designed. Of the 7 pairs that were dropped, 5 children fussed

109 out, 1 had an older sibling interfering with the study, and 1 was a twin (only the twin that

110 participated first was included). The final sample consisted of 41 children aged 24 mo.; 5

111 days to 29 mo.; 20 days ($M = 26$ mo.; 0 days), 21 of whom were girls.

112   In our recruitment, we made an effort to sample children from a variety of racial and

socio-economic groups. Our final sample was roughly representative of the racial composition

of the Chicago Area and the US more broadly (56% White, 27% Black, 8% Hispanic).

However, our sample was significantly more educated than the broader community (85% of

mothers had a College or Graduate Degree).

Stimuli

Eighteen animal images were selected from the Rossion and Pourtois (2004) image set,

a colorized version of the Snodgrass and Vanderwart (1980) object set. Animals were

selected based on estimates of their age of acquisition (AoA) for American English learners.

To obtain these estimates, we used two sources of information: parent-report estimates of

children's age of acquisition from Wordbank (Frank, Braginsky, Yurovsky, & Marchman,

2017), and retrospective self-report estimates of AoA from adults (Kuperman,

Stadthagen-Gonzalez, & Brysbaert, 2012, see Supplemental Materials for details). The AoA

of the selected animals ranged from 15 to 32 months. Half of the animals were chosen to

have an early AoA (15-23 months), and the other half were chosen to have a late AoA (25-32

months). Each trial featured three animals, all from either the early AoA or late AoA

category. This separation was designed to lower the likelihood that children could use

knowledge of early AoA animals to infer the correct target on late AoA trials.

A modified version of the MacArthur-Bates Communicative Development Inventory

Short Form (CDI; Fenson et al., 2007), a parent-reported measure of children's vocabulary,

was administered before the testing session via an online survey. The selected animal words

were added to the standard words, producing an 85 word survey. Two of the animal

words–one in the early AoA (pig) and one in the late AoA category (rooster)–were

accidentally omitted, so trials for those words were not included in analyses as we could not

obtain individual-level estimates of children's knowledge.
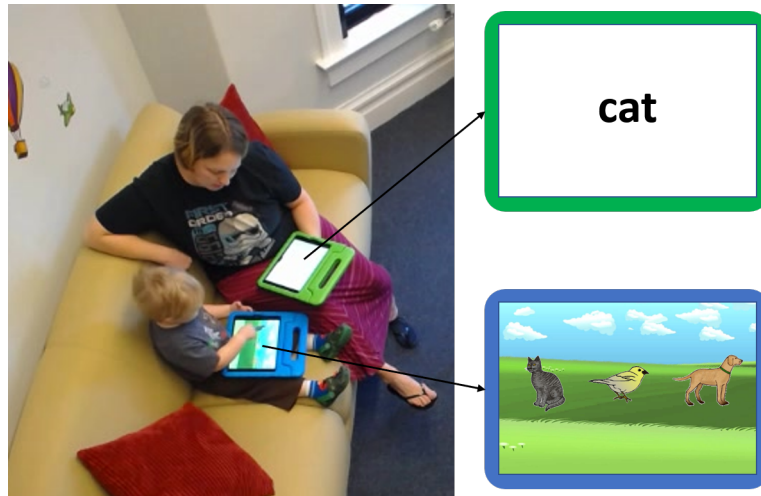
Figure 1. A parent-child dyad playing the reference game. On each trial, the parent's goal was to use language to communicate to their child which animal to choose.

Design and Procedure

Each parent-child pair played an interactive reference game using two iPads (Figure 1). Children began with two warm-up trials in which they tapped on circles that appeared on the iPads. Following these warm-up trials, children and their parents moved on to practice and then experimental trials. On each trial, three images of animals were displayed side by side on the child's screen, and a single word appeared on the parent's screen. Parents were instructed to communicate as they normally would with their child, and to encourage their child to choose the object corresponding to the word on their screen. The child was instructed to listen to their parent for cues. Once the child tapped an animal, the trial ended, and a new trial began. There were a total of 36 experimental trials, such that each animal appeared as the target twice. Trials were randomized for each participant, with the constraint that the same animal could not be the target twice in a row. Practice trials followed the same format as experimental trials, with the exception that images of fruit and vegetables were shown. All sessions were videotaped for transcription and coding.

Data analysis

Our primary quantity of interest was the amount of information that parents provided in each of their utterances. To approximate this, we measured the length of parents' referring expressions–the number of words they produced on each trial before their child selected an animal. Length is an imperfect proxy for information, but it is easy to quantify and theory-agnostic. Because utterance length is highly right-skewed (i.e. most utterances are short), we log-transformed length in all analyses. However, to facilitate interpretability, we show raw utterance length in our figures. Subsequently, utterances were manually coded for the following: (1) Use of an animal's canonical label (e.g., "leopard"), (2) Use of a descriptor (e.g., "spotted"), (3) Use of a comparison (e.g., "like a cat"), (4) Use of a superordinate level category label (e.g., "bird" for peacock), and (5) Use of a subordinate level category label (e.g., "Limelight Larry," a fictional character from a children's book, for peacock). Parent utterances irrelevant to the game (e.g. asking the child to sit down) were not analyzed. Children's utterances were coded when audible, but were not analyzed. Our second source of data was the vocabulary questionnaire that parents filled out prior to participation. Parents indicated whether their child produced each of the 85 words on the survey. In addition to analyzing parents' judgments for the animals in the task, we also computed the total number of words judged to be known for each child as a proxy for total vocabulary.

All of our analyses were done using mixed-effects models. In all cases we began with maximal random effects structures and pruned random effects until the models converged. We removed interaction terms before removing main effects, and opted to keep the most theory-relevant random effects when only a subset of main effects could be kept. For clarity, we present only the key findings and statistics here, but full model details can be found in the Supplemental Materials.

<div align="center">

Results

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We begin by confirming that our a priori divisions of animals into early and late age of acquisition (AoA) in the study design were reflected in parents' survey judgments, and that children were able to follow parents' references to select the correct target animal on each trial. After this, we show that parents fine-tune their referring expressions, producing more information in their references to animals that they think their individual children do not know. Further, parents update their tuning over the course of the experiment, producing more information on subsequent references to animals they thought their children knew but observed evidence to the contrary (i.e. children made an incorrect selection).

Target animal difficulty

We first confirm that the early AoA animals were more likely to be marked "known" by the parents of children in our studies. As predicted, parents judged that their children knew 94% of the animals in the early AoA category, and 33% of the animals in the late AoA category, which were reliably different from each-other (β = -6.48, p < .001, d = -3.57 [-4.48, -2.67]). Parents' judgments for each target word are shown in the Supplemental Materials.

Selection accuracy

On the whole, parents communicated effectively with their children, such that children selected the correct target on 69.05% of trials, reliably greater than would be expected by chance (33%, β = 2.07, p < .001, d = 1.14 [0.93, 1.36]). Children were above chance both for animals that parents thought they knew (M = 75.08%, β = 2.61, p < .001, d = 1.44 [1.18, 1.70]), and for animals that parents thought their children did not know (M = 55.19%, β = 1.23, p < .001, d = 0.68 [0.52, 0.84]). Thus, parents successfully communicated the target referent to children, even when parents thought their children did not know the name for the animal at the start of the game.

Was this accuracy driven by children's knowledge or parents' referential expressions?

200 To answer this question, we fit a mixed-effects logistic regression predicting children's

201 accuracy on each trial from children's total estimated vocabulary, parent-reported knowledge

202 of the target animal, and the (log) length of parents' expressions. We found that children

203 with bigger vocabularies were more accurate in general ($\beta = 0.40$, $p = .001$, $d = 0.22$ [0.09,

204 0.36]), and that children were less accurate for animals whose names parents thought they

205 did not know ($\beta = -1.86$, $p < .001$, $d = -1.02$ [-1.46, -0.58]) Longer referential expressions

206 were associated with lower accuracy for animals that parents thought their children knew

207 ($\beta = -0.40$, $p = .007$, $d = -0.22$ [-0.38, -0.06]), but greater accuracy for animals that parents

208 thought their children did not know ($\beta = 0.46$, $p = .025$, $d = 0.25$ [0.03, 0.47]).

209   Thus, longer referential expressions were associated with more successful

210 communication for animals that parents thought their children did not know, but were

211 unhelpful for animals that parents thought they did know. We next ask whether parents

212 tuned the lengths of their utterances appropriately, producing longer expressions for animals

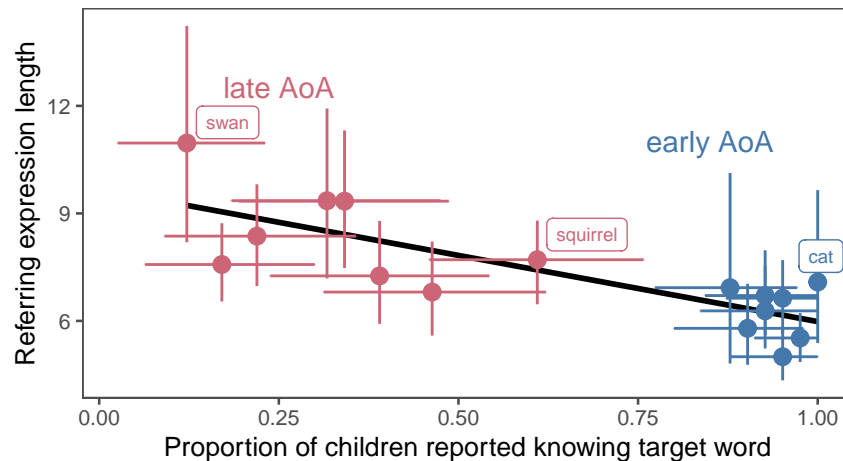213 they believe their children do not know.

Figure 2. Parents produced longer referring expressions to communicate about animals that children were generally less likely to know.
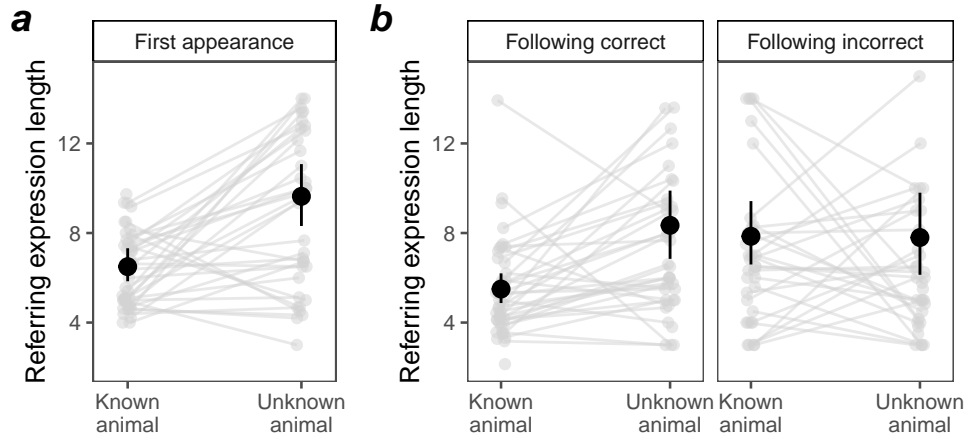
Figure 3. (A) Parents produced longer referring expressions for words that they thought their child did not know on their first apperance. (B) When children selected correctly in response to these expressions, parents continued to produce longer expressions for animals they thought their children did not know (left). However, if parents thought their child knew an animal, and they chose incorrectly, parents produced longer expressions on its second appearance (right). Gray points and lines represent individual participants, colored points and lines show group averaged proportions; error bars show 95% confidence intervals computed by non-parametric bootstrap.

Tuning

If parents calibrate their referring expressions to their children's linguistic knowledge, they should provide more information to children for whom a simple bare noun (e.g. "leopard") would be insufficient to identify the target. Parents did this in a number of ways: with one or more adjectives (e.g. "the spotted, yellow leopard"), with similes (e.g. "the one that's like a cat"), and with allusions to familiar animal exemplars of the category (e.g. "pick Midnight"). In many of these cases, parents would be required to produce more words (see below for further qualitative analyses). Thus, we first analyzed the (log) length of parents' referring expressions as a proxy for informativeness.

When do parents produce longer referring expressions? One possibility is that parents

224 tune at the coarsest level, using more words when speaking to children with smaller

225 vocabularies. This was not the case–the total number of words parents thought their children

226 knew did not reliably affect the length of their referring expressions (β = -0.02, p = .595, d

227 = -0.17 [-0.79, 0.45]). A second possibility is that parents have a sense for how difficult each

228 animal is in general, and tune coarsely to this. Our analyses confirmed this coarse tuning:

229 Parents said reliably fewer words for animals that more children were reported to know (β =

230 -0.17, p = .034, d = -1.19 [-2.26, -0.09]); Figure 3A). Finally, parents could fine-tune their

231 referential expressions to their children's individual knowledge, over and above the average

232 difficulty of each animal. Our analyses supported this conclusion: Parents used reliably fewer

233 words to refer to animals that they thought their individual child knew (β = 0.25, p = .003,

234 d = 0.98 [0.34, 1.61]); Figure 3B). Thus parents fine-tuned the amount of information in

235 their referential expressions, calibrating the amount of information they provided to their

236 children's knowledge, even after accounting for the average difficulty of the target animal.

237   In addition, because each animal appeared as a target twice, we asked whether parents

238 tuned their referential expressions over successive appearances. We found that parents used

239 fewer words on the second appearance of each animal (β = -0.08, p = .044, d = -1.06 [-2.07,

240 -0.03]), but that the difference in utterance length between animals they thought their

241 children knew versus didn't know was smaller on their second appearance (β = -0.14, p <

242 .001, d = -0.17 [-0.22, -0.12]). Why might that be? One possibility is that parents obtain

243 information from the first appearance of each animal: they may have thought their child

244 knew "leopard," but discovered from their incorrect choice that they did not. If so, they

245 might provide more information the second time around.

246   To test this prediction, we fit a model predicting the (log) length of parents' referring

247 expressions from appearance type (first, following correct, following incorrect), whether the

248 parent thought their child knew the animal prior to the experiment, and their interaction

249 between appearance type and prior belief. Relative to their utterances on an animal's first

250 appearance, parents produces shorter referring expressions on an animal's second appearance

251 following both correct responses (β = -0.14, p = .036, d = -0.12 [-0.23, -0.01]) and incorrect

252 responses (β = -0.28, p = < .001, d = -0.22 [-0.34, -0.11]). As before, parents produced

253 shorter utterances for animals they thought their child knew (β = -0.31, p = < .001, d =

254 -0.92 [-1.43, -0.41]). When children were correct on an animal's first appearance, parents

255 referring expressions on its second appearance did not differ in length based on whether they

256 thought their child knew the animal prior to the experiment (β = -0.02, p = .771, d = -0.02

257 [-0.13, 0.10]). However, when children were incorrect on an animal's first appearance, and

258 parents thought they knew the animal prior to the experiment, they produced reliably longer

259 referring expressions on it's second appearance (β = 0.43, p = < .001, d = 0.24 [0.13, 0.35];

260 Figure 3B).

261   As we predicted, when parents thought their children knew an animal, but then

262 observed evidence to the contrary, they provided more information in their referring

263 expressions for children to make the correct selection the second time. However, we did not

264 find the opposite pattern: When children were successful for animals that parents thought

265 they did not know, parents did not update their beliefs. Why should parents update their

266 beliefs in one direction but not the other? One likely explanation comes from parents'

267 linguistic tuning itself. Parents' goal in this task is to produce a referential expression that

268 allows their children to select the target animal whether or not they know its canonical label.

269 Consequently, when children select correctly on these trials, parents cannot know whether

270 their child actually knew the animal in question, or whether their referential expression

271 provided information that allowed the child to select the target despite not knowing its

272 canonical label.

273   Together, these two sets of analyses suggest that parents tune their referring

274 expressions not just coarsely to how much language their children generally know, nor their

275 knowledge about how hard animal words are on average, but finely to their beliefs about

²⁷⁶ their individual children's knowledge of specific lexical items. Further, when interaction

²⁷⁷ allows them to discover that they have incorrect beliefs about their children's knowledge,

²⁷⁸ they update these beliefs in real-time and leverage them on subsequent references to the

²⁷⁹ same lexical item.

²⁸⁰ **Content of referring expressions**
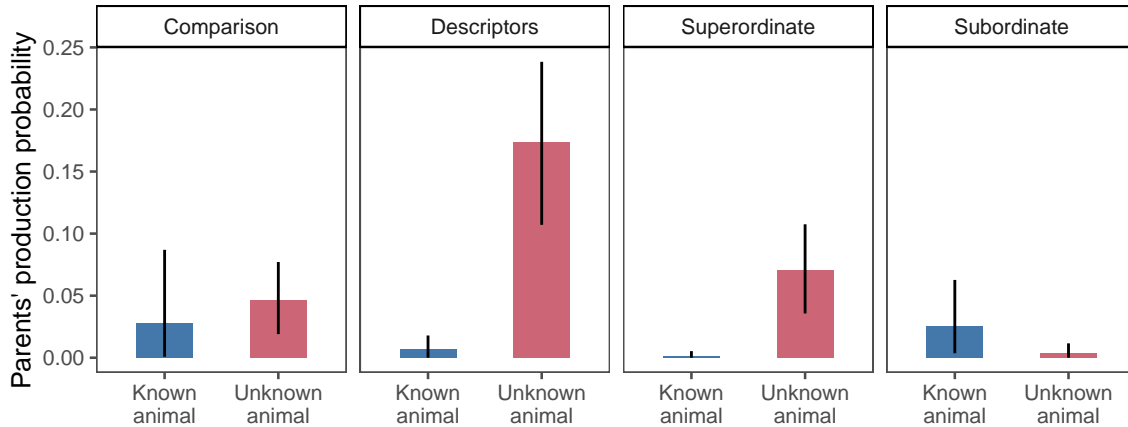
Figure 4. Proportion of trials where parents used comparison, descriptors, superordinate category labels, and subordinate category labels. Each panel shows proportions for andimals that parents thought their children knew and animals parents thought their children did not know.

²⁸¹   Parents produced reliably longer referring expressions when trying to communicate

²⁸² about animals that they thought their children did not know. In the analyses presented so

²⁸³ far, we used length as a theory-agnostic, quantitative measure of information. *How* did

²⁸⁴ parents successfully refer to animals that their children did not know? As a post-hoc

²⁸⁵ descriptive analysis, we coded five qualitative features of referring expressions: (1) Use of the

²⁸⁶ animal's canonical label (e.g., "leopard"), (2) Use of a descriptor (e.g., "spotted"), (3) Use of

²⁸⁷ a comparison (e.g., "like a cat"), (4) Use of a superordinate level category label (e.g., "bird"

²⁸⁸ for peacock), and (5) Use of a subordinate level category label (e.g., "Limelight Larry" for

²⁸⁹ peacock). Because the rates of usage of each of these kinds of reference varied widely

²⁹⁰ (e.g. canonical labels were used on 94.48% of trials, but subordinates were used on 1.21% of

trials), we fit a logistic mixed effects model separately for each reference kind, estimating whether it would be used on each trial from whether the parent thought their child knew the animal. Canonical labels were used on almost all trials, and did not differ in frequency between animals parents thought their children did not know ($M = 94.68\%$) and animals they thought their children knew ($M = 93.43\%$, $\beta = 0.43$, $p = .216$, $d = 0.23$ [-0.14, 0.61]). All other results are plotted in Figure 4.

Comparisons were used reliably more for animals parents believed their children did not know than for animals they thought their children knew, ($\beta = 2.29$, $p = .001$, $d = 1.26$ [0.49, 2.04]), as were descriptors ($\beta = 3.09$, $p < .001$, $d = 1.71$ [1.07, 2.35]) and superordinate category labels ($\beta = 3.01$, $p = .026$, $d = 1.66$ [0.20, 3.12]). Subordinates were used less for animals parents thought their children did not know than for animals they thought their children knew ($\beta = -2.19$, $p = .025$, $d = -1.21$ [-2.26, -0.15]). Thus, parents used a variety of strategies to refer to animals that they believed their children did not understand, but the use of descriptors was the most prominent. These descriptors are particularly apt to facilitate children's learning, connecting parents' fine-tuning for reference with their children's language acquisition.

Discussion

Parents have a wealth of knowledge about their children's linguistic development (Fenson et al., 2007). We show that parents draw on this knowledge to tune speech to their children in three ways: (1) they produce longer, more informative referring expressions for later-learned animals, (2) over and above this coarse tuning, parents tune information to their individual children's knowledge of specific animals, and (3) when children do not know an animal that parents thought they did, parents' subsequent references reflect this updated belief. Further, more informative referring expressions were associated with increased likelihood of successful communication: children were more likely to correctly select animals whose names they did not know if their parents produced longer utterances to refer to them.

Finally, we found that references to unknown animals were rich with descriptors and comparisons, helping children select the correct animal and potentially serving as a source of learning input.

These data are consistent with a strong form of the linguistic tuning hypothesis, in which parents fine-tune the information in their speech to children's language knowledge at the individual-word level. Why should this happen? Although parents' speech to children is unlikely to reflect a goal to teach, it is nonetheless goal-oriented: parents want to communicate successfully (Bruner, 1983). Fortunately, learning may piggyback on this optimization because of the inherent synergy between communication and learning–it is easier to learn from input that you understand (Yurovsky, 2018). Children bring powerful learning mechanisms to language acquisition, but these mechanisms are supported by an ecological niche designed for their success.

Acknowledgements

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