Lexical leveraging across the vocabulary spectrum: Different semantic properties support delayed and advanced learners

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Abstract

Toddlers better retain novel object-label mappings for items from taxonomic categories they have more knowledge in. Separately, words for concepts with more perceptual features are learned earlier than words for concepts with fewer perceptual features. Because these factors have only been examined separately, it is unclear whether effects of taxonomic density stem from differences in structured taxonomic knowledge or simply reflect lower-level differences in perceptual similarity among concepts. In the current study, we asked how taxonomic knowledge and perceptual information jointly contribute to word learning in a group of 24-month-olds with a wide range of vocabulary skill. We found that taxonomic knowledge facilitated word learning. We also found that the availability of perceptual cues to meaning was used as an additional support for word learning by children with smaller expressive vocabularies. Together these findings suggest that taxonomic knowledge is a better predictor of word learning compared to lower-level perceptual features at 24 months old. However, perceptual cues to meaning may provide additional support for vocabulary growth for learners with smaller vocabularies and/or late-talkers.

Keywords: vocabulary development; semantic features; taxonomic structure; perceptual information

Introduction

To what extent do young learners leverage their existing semantic knowledge to support word learning? A growing body of evidence suggests that word learning is affected by one's prior knowledge, positively (e.g., Borovsky, 2020; Borovsky et al., 2016a; Hadley et al., 2019) or negatively (James et al., 2023; Storkel & Adlof, 2009; Tamminen et al., 2013) depending on the learner's age and vocabulary size. In this paper, we seek to enrich this account by asking: *What semantic information specifically drives these effects?*

Adult lexicons encode relations between word meanings along multiple dimensions, such as taxonomic similarity (i.e., membership in hierarchical categories) and perceptual relations (i.e., shared features that are accessible to the senses). For example, CAT and DOG share taxonomic relations (both are mammals) and perceptual connections (both have fur). Each of these dimensions may have differing consequences for learning.

For learners with relatively small vocabularies – like toddlers – semantic category knowledge is positively linked to word learning. For example, toddlers' ability to sort objects into categories is linked to the onset of the vocabulary spurt (Gopnik et al., 1996; Gopnik & Meltzoff, 1992; Poulin-Dubois et al., 1995). This connection suggests that toddlers' ability to impose hierarchical organization on concepts facilitates learning new words/concepts. More directly, language processing and word learning are facilitated in semantic domains for which toddlers have relatively more knowledge. For instance, Borovsky and colleagues (2016b) found that 24-month-olds were faster to fixate on familiar targets from domains they had relatively denser vs. sparser knowledge in and showed more robust anticipatory fixations toward thematically appropriate direct objects from denser semantic domains (e.g., looking to a car after hearing "you can drive the…"). Further, novel word learning is facilitated in relatively denser semantic categories (Borovsky et al., 2016a). Specifically, following ostensive labeling, 24-month-olds looked more robustly toward novel targets (low frequency items from early acquired categories) that came from categories they had more (vs. less) knowledge in. Finally, semantic category knowledge helps children deal with challenging word-learning conditions. That is, when words are taught in conditions that introduce ambiguity in the word-referent mapping (i.e., in a mutual exclusivity task), only words with dense category knowledge show evidence of learning (Borovsky, 2020).

Perceptual elements of meaning can also support early word recognition and learning (Quinn & Eimas, 1997; c.f. Smiley & Brown, 1979). For example, early learned words tend to be concrete, imageable, and have salient perceptual

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features (Caselli & Pyers, 2017; Della Rosa et al., 2010; Gilhooly & Logie, 1980; Hansen, 2017; McDonough et al., 2011; Perry et al., 2017; Pruden et al., 2006), and children learn perceptual regularities across objects (Rakison, 2003). The shape bias – a tendency for leaners to extend new labels to objects that match the shape of the initial exemplar (Landau et al., 1988) – is one well-documented perceptual advantage in word learning. Attentional learning accounts suggest the shape bias emerges as children learn to attend to perceptual features that provide informative and reliable cues to word meaning, with shape being one (but not the only) informative perceptual cue (Colunga & Smith, 2005; Smith et al., 1996, 2002; Smith & Samuelson, 2006). Toddlers also learn words earlier when they have more perceptual features in common with words that they already know (Kueser & Borovsky, in press; Peters & Borovsky, 2019). Known words with more perceptual feature connections to other known words are recognized more accurately in online comprehension than known words with fewer perceptual connections (Peters, Kueser, & Borovsky, 2021). Finally, words with meanings that involve more distinct sensory modalities are learned earlier according to parental vocabulary checklists and are recognized more quickly in a looking-while-listening task (Seidl et al., 2024). Thus, the availability of perceptual features of concepts supports early word learning and semantic representation.

Taxonomic category density and perceptual richness are also correlated. For instance, all mammals have hair/fur (a defining perceptual characteristic of category membership), and all mammals have mammary glands to feed their offspring (a defining functional characteristic of category membership). As adults, we may view the biological trait <*has_mammary_glands*> as more central in organizing the mammal category relative to <*has_hair*> – a hairless cat is a mammal, and a fuzzy caterpillar is not. However, the cooccurrence of perceptual features among category members may provide a reasonable early superordinate category representation. Models of lexical organization constructed with perceptual features of early learned nouns resemble the hierarchical taxonomic structure of adult lexical networks (Hills et al., 2009a). Therefore, it is possible that what has been construed as effects of higher-order taxonomic structure in prior work were driven by low-level perceptual feature overlap among category members.

What's more, relations between taxonomic or perceptual information and word learning may change as children's vocabularies grow. Several findings suggest that sensitivity to taxonomic information increases with vocabulary size. For example, in semantic priming studies, 24-month-old children reliably show taxonomic and associative priming, while taxonomic priming effects with 21-month-olds are not consistent (Arias-Trejo & Plunkett, 2009). The influence of taxonomic structure on learning and priming also varies with vocabulary size at 24 months (Borovsky et al., 2016a; Rämä et al., 2013a). Other work shows that for adults and children with larger vocabularies, taxonomic category density may impair word learning due to increased interference (James et al., 2023; Storkel & Adlof, 2009; Tamminen et al., 2013).

To explore how these effects may change as early vocabularies grow, we compare late talkers (LTs) to children with typical development (TD). LTs – toddlers who fall at the low end of the vocabulary learning spectrum – differ from their TD peers in their use of perceptual supports for word learning. For instance, TD children tend to extend labels to novel exemplars based on shape (the shape bias), whereas LTs fail to extend labels systematically on the basis of object shape (Colunga & Smith, 2005; Jones, 2003; Perry & Kucker, 2019). Thus, the influence of perceptual information in word learning may vary by language status (LT vs. TD). In addition, as LTs have smaller vocabularies, they also have less taxonomic knowledge, suggesting they may derive less benefit from taxonomic information in word learning compared to peers with TD.

The Current Study

We examined how different types of semantic relations between words support learning in children with varying vocabulary size. Specifically, we ask how semantic category knowledge and perceptual features of concepts jointly contribute to learning and real-time recognition of novel words in 24-month-olds with wide variation in language skill, including children with LT and TD. The current study design is, in part, based on Borovsky et al. (2016a), which found that 24-month-olds' word learning was facilitated for categories that were higher (vs. lower) in density according to the child's own expressive vocabulary. We expand on this design by exploring whether the availability of perceptual cues to meaning affects novel word learning, how this factor interacts with taxonomic category density, and how each factor (category density and perceptual richness) interacts with vocabulary size to predict learning.

To address our research questions, we measured 24-month-olds' retention of novel object-label mappings following an ostensive word learning period. We used a 2x2 within-subjects design to explore how higher and lower taxonomic category density and higher and lower perceptual richness contribute to word learning individually and in combination. We also explored how vocabulary size interacted with these factors to predict word learning.

Predictions We expected toddlers to successfully map novel words to their intended referents, resulting in greater looking toward the target relative to the distractor image during test trials. We also expected taxonomic and perceptual information to facilitate word learning, leading to more robust visual fixations to target images. If taxonomic and perceptual information interact, we expected a larger effect of perceptual richness in lower-density (vs. higher-density) categories. Finally, we expected that toddlers with larger vocabularies would show an increased effect of category density because accessibility of taxonomic information is related to vocabulary size (Chow et al., 2019; Rämä et al., 2013b), and would show decreased effects of perceptual richness indicating a decreasing reliance on perceptual information as vocabularies grow.

Methods

Participants

One hundred and thirty-five (135) 24-month-olds (*M* age = 24.4 months, range = 23.7 – 25.9 months) contributed data to the analyses. The demographic distributions in this sample are representative of the geographical region in which data was collected. Thirteen additional children were invited to participate but excluded for failing to meet the inclusionary criteria (6), not attempting the eye-tracking task (1), or not contributing enough trials following data cleaning (6).

Materials

Item Selection We systematically manipulated taxonomic density and perceptual richness within subjects. We used a 2x2 design in which each factor (category density and perceptual richness) had two levels (higher or lower). We identified four taxonomic categories that are familiar to toddlers and were used in a prior experiment with a similar design (Borovsky et al., 2016a): animals, drinks, fruits, and vehicles. Category density was assigned based on each individual toddler's existing vocabulary knowledge. We chose two unfamiliar words in each category, so each category had one item with low perceptual richness and one item with high perceptual richness. Perceptual richness was defined as the raw count of normed perceptual features of each item (see Borovsky et al., 2023 for norming procedure). The underlying assumption is that by having more perceptual features it is more likely that a concept will relate to other concepts in this way. There was a total of eight novel items, two per category.

Table1: Proportion kids assigned H/L density by category

Category	High Density	Low Density
Animals	0.60	0.40
Drinks	0.47	0.53
Fruits	0.32	0.68
Vehicles	0.61	0.39

Visual Stimuli Novel items were depicted using photorealistic images that were 400 x 400 pixels in size and centered on a white background.

Audio Stimuli Audio stimuli were recorded in infant-directed speech by a female native speaker of General American English. Ostensive labels for training trials were adjusted to a duration of 12,466ms during which the novel label was repeated five times. Target object labels for test trials were adjusted to a duration of 660ms.

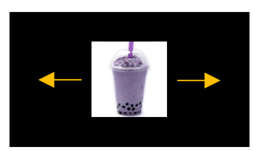
Vocabulary Assessment We used the MacArthur Bates Communicative Development Inventory: Words and Sentences form (MBCDI; Fenson et al., 2007) as a measure of expressive vocabulary composition. Vocabulary percentiles in this sample ranged from the 1st to the 99th percentile (*M* = 47.40, *Mdn* = 50.00, *SD* = 29.10). Toddlers' vocabularies ranged from 1 to 639 words (*M* = 271.10, *Mdn* = 261.00, *SD* = 167.85).

Procedure

All assessments were completed across two laboratory visits that lasted 1 hour each. We aimed to schedule the second visit within 14 days of the first, but occasionally had to schedule outside this window due to family illness or scheduling constraints (*M* # days between visits = 8.5, range = 0-35).

The design contained 4 experimental blocks and 32 total trials. Novel items appeared as yoked pairs with one pair per block. Items were paired such that within pairs the items came from different categories (therefore, different densities) and one item had higher perceptual richness and one had lower perceptual richness. Each block began with four training trials (two per word) in which the novel object moved back and forth across the screen while the novel label played five times, for a total of ten labeling instances per novel item. This was followed by four test trials (two per novel word) in which both items were displayed, and one was labeled. Each test trial began with a 2000ms silent visual preview of the images. Next, a gaze-contingent central fixation appeared with an auditory cue ("Look!" or "Ooh!") and remained on screen until the toddler fixated the image for 150ms. Finally, the label of the target novel object played (e.g., "Boba!"). An encouragement phrase was played 2000ms after label onset (e.g., "Good job!"). The trial ended 4000ms after label onset; eye movements were recorded from the beginning of the preview period through the end of the trial. See Table 2 for trial examples. Test trials were separated by 1-3 filler trials with familiar objects and words, which were included as part of another experiment.

Table 2: Example training and test trials

Phase	Visual Scene	Audio
Training		*"Look! Boba. That's a boba. Do you see the boba? Cool! That's a boba."* [12000 ms]
Test		Silent Preview [2000 ms] *"Look"* +Center Fix. Image [Gaze-contingent] *"Boba! Good job!"* [4000 ms]

The experiment was counterbalanced such that target objects appeared equally on the left and right side of the screen during test trials within and across lists, and the target and distractor objects were labeled an equal number of times. We additionally counterbalanced the stimuli to account for the order the words were presented in during training and test. This resulted in a total of 24 counterbalance lists. The eye-tracking task was split across visit days; toddlers completed half of the task on visit day one and half on visit day two.

Eye movements were recorded with a SR Research Eye-Link 1000+ eye-tracker in a remote arm configuration at a sampling rate of 500Hz, with a manual 5-point calibration and validation procedure.

Caregivers were asked to complete the MBCDI one week prior to the first lab visit.

Data Processing

Eye-tracking Data Cleaning We binned target and distractor looking proportions into 50ms bins. We excluded trials in which participants failed to attend to either of the Interest Areas (IAs) for at least 20% of the trial period (*N* = 103 trials, 5% of trials). We removed participants that did not retain at least two trials per condition (*N* = 6 participants). The final sample includes 1,876 trials.

Calculating Log Gaze We calculated log-adjusted target advantage scores (i.e., log gaze) in each bin as the log of the proportion of looking to the target over the proportion of looking to the distractor (ln[target_prop/distractor_prop]). Because values of 0 are undefined by this formula, we replaced 0 values with a value corresponding to half the value of the smallest observable nonzero target or distractor looking proportions before performing the log adjustment. This log gaze procedure follows prior work (see e.g., Arai et al., 2007). We use log gaze because it is not limited to values between 0 and 1 making it a more appropriate outcome measure for linear regression analyses.

Higher and Lower Category Domain Assignment For each child, we used their MBCDI report to calculate the proportion of words within each category (animals, fruits, drinks, and vehicles) that the child said out of the total number of words in the category. The two categories with the highest proportions were assigned to higher-density and the two categories with the lowest proportions were assigned to lower-density.

Talker Status Assignment We labeled toddlers whose MBCDI scores were below the 20^{th} percentile (based on instrument norms) as LT and toddlers at or above the 20^{th} percentile as TD (LT = 26, TD = 109).

Results

Figure 1 depicts the time course of target vs. distractor looks by category density and perceptual richness. The black box marks our preplanned analysis window (500-2000ms post label onset). During this window, all lines are above 0, suggesting that toddlers recognized targets. In the analysis window, toddlers appear to better recognize words from categories in which they have more knowledge. There does not appear to be an effect of perceptual richness on word recognition, confirmed via inferential statistics (Table 3).

Planned Analysis

To examine the effects of category density, perceptual richness, and vocabulary size on novel word retention, we fit a linear mixed effects regression model (Table 3) to participant-by-trial log gaze data averaged across our 500-2000ms analysis window. This model included fixed effects of category density, perceptual richness, and vocabulary size. We also included all possible 2-way interactions among these factors. The model included by-subject and by-item random intercepts. All categorical variables were sum coded (.5, -.5) and continuous predictors were centered and scaled.

Three key findings emerge from this analysis. First, the model intercept is significant and positive, indicating that across conditions toddlers successfully mapped the novel words to their depicted target objects (Estimated Marginal Mean (EMM) log gaze = .30, SE = .11). Second, we observed a main effect of category density. Toddlers looked more to targets (relative to distractors) from higher-density categories (Higher-density: EMM = .49, SE = .12; Lower-density: EMM = .12, SE = .12). Third, we observed a significant interaction between vocabulary size and perceptual richness, depicted in Figure 2, such that children with smaller vocabularies looked more to targets that were higher in perceptual richness than lower in perceptual richness.

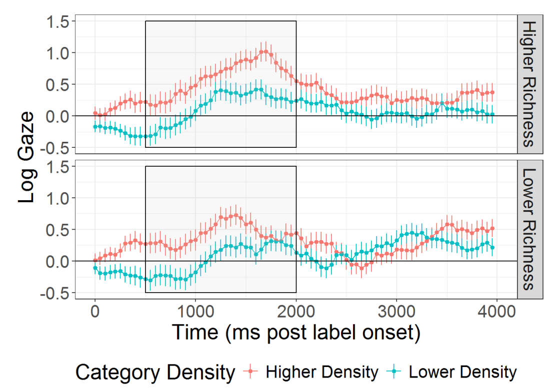


Figure 1: Word learning by category density and perceptual richness. Log gaze values greater than 0 indicate greater looking to targets relative to distractors. Error bars are SE.

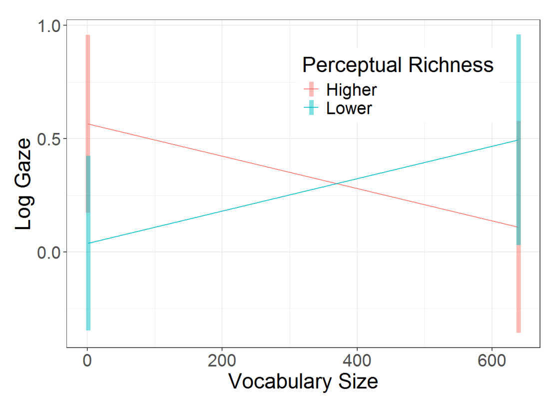


Figure 2: Estimated marginal means of log gaze at higher and lower levels of perceptual richness by vocabulary size.

Table 3: Planned linear mixed effects regression results.

Effect	Estimate	95% C.I.	t
Intercept	**.30**	**[.08, .53]**	**2.68***
Category Density	**.37**	**[.18, .57]**	**3.77*****
Perceptual Richness	.16	[-.18, .50]	.89
Vocab. Size	-.00	[-.12, .12]	.00
Density*Richness	.04	[-.34, .43]	.22
Vocab.*Density	-.08	[-.28, .11]	-.86
Vocab.*Richness	**-.23**	**[-.42, -.04]**	**-2.42***
Note. * $p < .05$, ** $p < .01$, *** $p < .001$.			

Exploratory Analysis

To better understand the nature of the relationship between vocabulary knowledge and perceptual richness in novel word learning, we conducted post-hoc analyses which split the data categorically by Talker Status (LT or TD). We asked whether toddlers who are late-talkers would perform differently from toddlers who are typically developing. We ran a linear mixed-effects regression with fixed effects of category density, perceptual richness, and talker status (LT or TD), and the interactions of category density with perceptual richness, category density with talker status, and perceptual richness with talker status. The model included by-subject and by-item random effects. We used sum coding for all fixed effects. Due to the imbalance in talker status groups, we weighted the codes for this factor. This model is summarized in Table 4.

These post-hoc result patterns mirror the planned analysis. First, the model intercept is significant and positive indicating that toddlers learned the intended novel mappings (EMM = .28, SE = .12). Second, we observed a main effect of category density such that toddlers looked more robustly to targets from semantic categories they had more knowledge in (Higher-density: EMM = .48, SE = .14; Lower-density: EMM = .09, SE = .14). Finally, we observed an interaction of talker status with perceptual richness. Children with LT looked more robustly toward targets with more perceptual richness, while children with TD did not (see Figure 3). This pattern suggests that LT toddlers use perceptual and taxonomic information to support learning while more advanced learners prioritize taxonomic relations for learning.

Table 4: Post-hoc linear mixed effects regression results.

Effect	Estimate	95% C.I.	t
Intercept	**.30**	**[.08, .53]**	**2.69***
Category Density	**.37**	**[.18, .57]**	**3.75*****
Perceptual Richness	.15	[-.20, .50]	.83
Talker Status	.07	[-.21, .36]	.51
Density*Richness	.05	[-.34, .43]	.23
Talker*Density	-.07	[-.54, .40]	-.29
Talker*Richness	**-.73**	**[-1.2, -.26]**	**-3.07****
Note. * $p < .05$, ** $p < .01$, *** $p < .001$.			

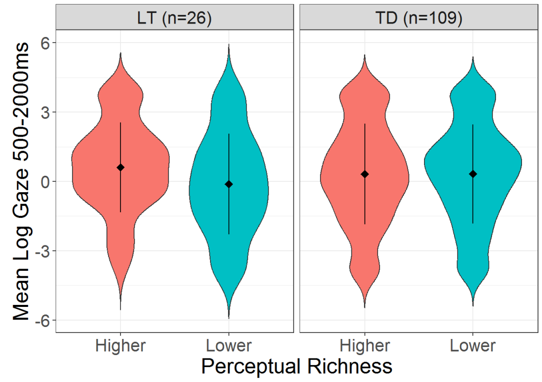


Figure 3: Distribution of log gaze in the analysis window by perceptual richness across children with LT and TD. Diamonds mark the mean of each distribution and vertical lines mark the standard deviation.

Discussion

Prior findings suggest a faciliatory effect of semantic category knowledge on word learning (Borovsky, 2020; Borovsky et al., 2016a). Yet, because taxonomic density effects had only been examined in isolation, it was difficult to disentangle whether these effects stemmed from perceptual overlap among category members or whether the effects were attributable to reasoning over higher-order conceptual structures. To address this gap, the current study examined the joint contribution of taxonomic and perceptual cues to meaning on word learning in a group of 24-month-old children. Three key findings emerged from this work: First, 24-month-olds who had a wide range of current vocabulary skill successfully learned novel words. Second, toddlers leveraged their own taxonomic knowledge to support word learning. Third, children with smaller productive vocabularies, including LTs, used the availability of perceptual cues to support word learning, while children with larger productive vocabularies did not. We discuss the implications of each finding in turn below.

Finding 1: Toddlers with a range of vocabulary skill learned new words

Across conditions, toddlers in the current sample successfully learned novel words in our experiment. This finding is noteworthy given the wide range of vocabulary ability among our sample, which included a significant proportion of children with LT. In the literature on late talking, studies show mixed results regarding LTs' abilities to learn new words in similar experimental contexts, with some studies reporting negative results (Ellis Weismer et al., 2013; Macroy-Higgins & Montemarano, 2016) and others reporting positive results (Ellis et al., 2015; LaTourrette et al., 2023). One key feature of our experiment, and of others with positive results, is that the experiments involved simpler parameters including test phases immediately following the learning phase as well as teaching fewer novel words and including more labels in training. Thus, these findings point to the possibility that children at the lower end of the vocabulary learning spectrum may have difficulty retaining these mappings over time and/or may require more training to show robust learning. However, further investigation is needed to verify this, as well as understand the implications for vocabulary growth.

Finding 2: Toddlers leverage taxonomic organization to support word learning

We explored the role that semantic category knowledge played in word learning while controlling for the availability of perceptual cues to meaning. Because the prior research only examined taxonomic density alone, it was unclear whether semantic density's impact on word learning could be attributed to higher-order conceptual organization or reflected lower-level perceptual overlap among category members. We found that, when controlling for the availability of perceptual cues to meaning, toddlers showed novel word learning advantages when they knew many other words in the semantic category to which the novel word belonged. Importantly, higher- and lower- density was defined in relation to each individual child's knowledge within the semantic categories we probed. This suggests that children build on higher-order conceptual structures to support word learning. In contrast to our *a priori* predictions, toddlers' reliance on taxonomic information did not increase with vocabulary size, which indicates that 24-month-olds with a range of vocabulary skills can use taxonomic structure to support word learning. More generally, while children younger than 24-months may not consistently have access to taxonomic structures (see Arias-Trejo & Plunkett, 2009), our data suggest that by 24-months children not only have access to taxonomic structures (see also Arias-Trejo & Plunkett, 2013; Willits et al., 2013) but also use this information to support vocabulary growth that reflects adult-like conceptual hierarchies of knowledge.

Finding 3: Perceptual richness and vocabulary size/skill interact to predict word learning

Previous work modeling the normative growth of early acquired semantic knowledge indicates that words/concepts with a greater number of perceptual features are acquired earlier in development than words/concepts with fewer available perceptual features (Kueser & Borovsky, in press; Peters & Borovsky, 2019). It was on this basis that we predicted that the availability of more perceptual cues to meaning would better support word learning. While the data did not support a universal perceptual richness "boost" for word learning across children, we found that perceptual richness differentially supported toddlers' learning as a function of vocabulary size/skill. Specifically, we found that children with smaller productive vocabularies and LT profited from availability of perceptual cues to meaning, but children with larger productive vocabularies did not.

These findings pattern with recent work about toddlers' ability to process language under conditions of semantic interference (Kueser, et al., under review). Specifically, Kueser et al. found TD infants experienced interference from taxonomic information, recognizing words less accurately when competing referents were from the same superordinate category, but did not experience interference from perceptual overlap among available referents alone. In contrast, LT infants experienced semantic interference in conditions of perceptual-only overlap, as well as taxonomic overlap. This finding, as well as our results, suggest that children with smaller productive vocabularies attend more to perceptual aspects of meaning than children with larger vocabularies.

These findings also highlight an important developmental question: Do the observed differences in how children with less advanced vocabulary development attend to perceptual dimensions of meaning reflect a typical developmental trajectory, or are they indicative of an underlying language-learning difficulty? This question is particularly important as a quickly emerging body of research suggests that LT children differ from their TD peers in vocabulary structure/composition in addition to vocabulary size (Beckage et al., 2011; Hills et al., 2009a, 2009b). While many children with LT will "catch-up" to their TD peers, roughly 20-30% will experience persistent language difficulty (Dale et al., 2003). Thus, it is crucial to better understand the nature of these differences and how they emerge.

The current pattern of findings can be viewed as a delay in language learning: variation in early word learning abilities may reflect individual differences in the pace of learning, where LT children have less access to taxonomic information simply because they know fewer words. This pattern could also suggest a deficit in children at the low end of vocabulary growth: LTs may fail attend to the most informative dimensions of meaning (i.e., taxonomic categories), a bias that may slow further growth in vocabulary and potentially point to risk factors for developing language difficulties during the school years. This is potentially aligned with studies described above which find that LT and TD children differ in their use of a shape bias to guide word learning (Colunga & Sims, 2017; Jones, 2003; Perry & Kucker, 2019). However, keeping in mind recent work demonstrating that perceptual features predict the normative age of acquisition for many early acquired words (Peters & Borovsky, 2019), we argue that these findings more likely reflect the continuous nature of language learning. To disentangle the question under discussion, future work is needed to better understand the role that perceptual information plays in early word learning and conceptual development.

Conclusion

We found that while word learning was largely successful, word learning was also facilitated when new words belonged to semantic categories about which children had more knowledge. We also found that perceptual information provided an additional boost to word learning for children with smaller vocabularies and LT. This suggests that taxonomic knowledge is a better predictor of word learning compared to lower-level perceptual features in 24-month-old learners, and perceptual cues to meaning may provide support for vocabulary growth at the start of development, particularly for learners with smaller vocabularies and/or LT.

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