The role of verbal labels in attention to dimensional similarity

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Abstract

In general, young children focus on holistic similarity and older children focus on dimensional similarity (selectively attending to one property, such as brightness, to the exclusion of others, such as size). Research on early word learning, however, suggests the process of learning words trains attention to category-relevant dimensions. We ask: does word learning scaffold dimensional attention more generally? By showing labels support dimensional attention, these results clarify the processes involved in similarity perception and unify our understanding of attentional processes in word learning with those in a broader context.

Keywords: Labels; categorization; selective attention.

Over the course of development, we become increasingly skilled at attending to one thing to the exclusion of others (see Hanania & Smith, 2010 for review). For example, adults can easily focus on the color of a lime, rather than its exact shape or size, in order to distinguish it from a lemon. Evidence that older children and adults are generally much better than younger children at selectively attending to one dimension to the exclusion of others comes from a variety of domains, but we still do not know the process by which such changes occur. The goal of this paper is to explore the processes driving changes in selective attention with respect to their effects on similarity perception.

Of particular relevance to the current study is the holistic-to-dimensional shift, or the tendency for young children to focus on holistic similarity and older children and adults to focus on dimensional similarity relationships (Smith & Kemler, 1977). Imagine you are presented with an orange, a yellowish-orange ball, and a yellowish-orange toy car. If you are an adult, you would be more likely to group the ball with the car because they match exactly along one dimension (i.e. identical in color). A young child, however, would group the orange with the ball because they are similar along multiple dimensions (i.e. shape and color)—they are holistically similar. This shift in similarity perception occurs during the early school-age years, such that younger children (<8-years-old) tend to be holistic classifiers and older children dimensional classifiers. Free classification, such as the triad classification task pictured in Figure 1, is the standard task used to examine this shift. As can be seen, two stimuli (A and B) match on one dimension (e.g. size) but vary greatly along another dimension (e.g. brightness). The third stimulus, C, is highly similar to A along both dimensions, but not identical to it on either. If a participant were using holistic similarity, she would classify A and C together. If a participant were using dimensional similarity, she would classify A and B together. Smith and Kemler (1977) found that 5-6 year-olds made mostly AC matches and 10-11 year-olds made mostly AB matches.

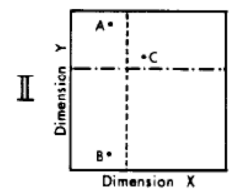

Figure 1: Schematic representation of stimuli used in Smith and Kemler's 1977 triad classification task.

One explanation for this change comes from what we know about the role of word learning in the development of dimensional attention and categorization. For example, Landau & Shipley (2001) demonstrated that when two objects are given the same label, participants generalize it to all intermediate morphs between the objects. If the two objects are given different names, participants divide the intermediates into two distinct categories. Lupyan and colleagues (2007) demonstrated that labels facilitated adults' category learning. Importantly, in this example, the labels were task irrelevant, providing information redundant with category structure. Other researchers have argued that redundant associations between cues strengthen the associations between other perceptual cues and category structure and that the facilitative effect of labels is fundamentally *developmental* (Yoshida & Smith, 2005). By this view, over the course of word learning, the frequent redundancy between labels and other cues such as solidity, syntax, and category organization helps children use labels to facilitate learning. The more experience children have learning regularities in these overlapping cues, the better they can attend to relevant dimensions of similarity, at least in the context of further word learning.

This is most clearly seen in the development of word-learning biases. For example, children acquire a shape bias, or the tendency to generalize names of novel objects by similarity in shape (Landau et al., 1988). This bias emerges from regularities present in the linguistic environment: a majority of the early words children learn name categories of solid objects organized by similarity in shape, e.g., ball.

As children learn more words, their attention is trained such that they automatically attend shape when learning names for solid objects. Smith and colleagues (2002) therefore describe word learning as "on-the-job training for attention," and have shown teaching children names of categories organized by similarity in shape leads them to precociously attend to shape when learning new words. As they learn words that name categories organized in other ways, e.g., names for nonsolids in categories organized by similarity in material or adjectives that name properties of objects, they acquire other biases and learn to flexibly attend to context-appropriate dimensions.

Over development, learning words directs children's attention to dimensional similarity in future word learning Thus, the critical unanswered question, however, is whether learning words also directs children's attention in non-linguistic contexts. We propose word learning provides on-the-job training for attention more globally: in particular that labels scaffold dimensional attention in similarity perception. The regularity between words and attending to dimensional similarity leads to a higher-order association between labels and attending to dimensional similarity. According to our hypothesis, then, the tight links between labels, categorization, and dimensional similarity should gradually lead to a bias for dimensional similarity even outside of a labeling/word learning context. In 2 experiments we asked: 1) if there are developmental differences in category learning related to dimensional attention in similarity classification, and 2) if labels can support dimensional attention and facilitate categorization.

Experiment 1

Experiment 1 examines if developmental differences in attention to dimensional similarity affect category learning.

Methods

Participants 33 5- to 8-year-old children participated. One child did not complete the experiment, thus there were 32 children in the final group.

Stimuli The stimuli were squares varying metrically in size and brightness (see Goldstone, 1994) and were presented on a pc with a touch screen monitor using Eprime 2.0.

Procedure Children completed a triad pretest and were divided into classifier groups based on performance on this task (Smith & Kemler, 1977). There were 16 holistic classifiers (chose primarily holistic matches) and 16 dimensional classifiers (primarily dimensional matches).

Children next completed the category-learning task and category test. In the category-learning task children were presented with a square (a "rock") and asked to decide to which of two categories it came from (the ocean or jungle) by touching a picture on the computer screen. During the learning task, children received auditory feedback regarding accuracy of each decision (bell or buzzer sound). Learning blocks were made up of 8 trials, 4 trials for each category. Half of the children in each classification group were trained with categories organized by similarity in size (size learners), half with brightness (brightness learners). The learning criterion was getting 7 out of 8 trials per block correct, 2 blocks in a row. If a child did not reach criterion after 30 blocks, the learning phase ended. The learning task was followed by the category test, where no feedback was given after each trial. Stimuli used at test included exemplars from training and 6 novel exemplars from each category. The test consisted of 4 blocks of 20 trials.

It was expected that dimensional classifiers would be able to learn the categories and generalize to novel category exemplars, but that holistic children should have more difficulty. For both groups, correct categorization of novel exemplars should require learning something about category organization rather than something about specific stimuli.

Next, children completed the discrimination task that measured their ability to distinguish between close values on test dimensions. Children were presented with a target and two test stimuli and asked to indicate which of the test stimuli matched the target by touching it. All three stimuli were present until the children responded. The target matched one of the test stimuli on every trial. Discrimination was tested both within and across category boundaries. All pairs were presented four times—each stimulus within a pair was presented twice as target and matching test item, and twice as foil—for a total of 96 trials. All children were presented with the same pairs, such that any given trial forced children to discriminate along a dimension that was only relevant for one group's learned category: e.g., a pair that differed only in size would test discrimination along the relevant dimension for the size-learners and the irrelevant for brightness-learners. This allowed examination of changes in children's ability to make discriminations along category-relevant and irrelevant dimensions and within and between categories.

Finally, children completed a posttest triad task that was identical to the pretest version. Children who were dimensional classifiers on the triad pretest should still classify dimensionally as learning categories should not decrease their ability to selectively attend to dimensional similarity. Similarly, children who were holistic classifiers on the triad pretest should still classify holistically.

Results and Discussion

Category learning It was expected that dimensional classifiers would be able to learn the categories but that holistic children would have more difficulty. To examine this, we measured the number of blocks to criterion for each child in the category-learning task (see Figure 2). A linear mixed regression model of the interaction between classifier type (holistic v. dimensional) and category structure (brightness v. size organization) on the number of blocks it took children to reach criterion, revealed a significant effect of classifier type such that dimensional classifiers were faster to reach criterion than holistic classifiers, t=21.88, p<.0001. (Because of the difficulty in determining degrees of freedom in linear mixed models, we conducted MCMC sampling to find p-values). This model also showed an effect of category structure such that children were faster to reach criterion when learning categories organized by brightness, t =-23.00, p<.0001. This brightness advantage replicates Goldstone's (1994b) finding with adults. There was also an interaction between classifier type and category structure such that holistic classifiers showed less of a difference in speed of learning brightness and size categories than dimensional classifiers, t=2.66, p<.01. Thus, children who were able to selectively attend to a single dimension learned a novel category distinction based on one dimension faster than children who were holistic attenders. However, because dimensional classifiers were generally older than holistic classifiers, it is possible age could be the basis for these results. However, a model with both classifier type and age was significantly better than one with only age, $X^2(1)$ =12659, p<.0001, but no different from one with only classifier type. Thus classifier type, but not age, was necessary to account for findings.

We next examined performance in the other tasks using logistic mixed regression. These analyses included only data from children who reached learning criterion. We report results of classification groups separately because we are interested in whether dimensional and holistic classifiers both show, for example, enhanced between-category discrimination, than whether dimensional classifiers are more accurate than holistic classifiers. Because other researchers have found differences in learning brightness and size categories (e.g. Goldstone 1994), we examined performance of these groups separately. Results of regression models (z and p values) are reported in Table 1.

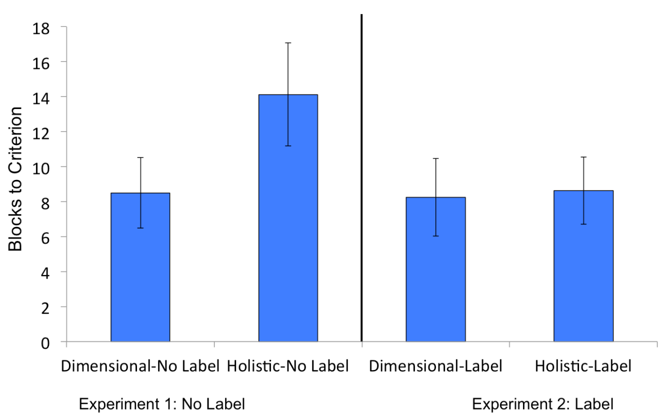

Figure 2: Number of blocks to criterion in category learning.

Category test We expected dimensional classifiers to generalize to new exemplars but that this should require learning something about category organization rather than about specific stimuli. Overall, children were very accurate in the categorization test. Dimensional classifiers who learned brightness categories, M=.87, $t(7)$=41.61, p<.0001, dimensional classifiers who learned size categories, M=.77, $t(6)$=4.98, p<.01, holistic classifiers who learned brightness categories, M=.83, $t(6)$=6.33, p<.001, and holistic classifiers who learned size categories, M=.70, $t(4)$=3.01, p<.05, were all significantly better than chance.

Logistic mixed regression reveals that both dimensional classifiers who learned brightness and who learned size categories categorized familiar and novel stimuli equally well. Similarly, both holistic classifiers who learned brightness and who learned size categories categorized familiar and novel stimuli equally well. These results suggest both groups might have learned about the category-relevant dimension rather than specific stimuli.

Discrimination Goldstone (1994) found an advantage for relevant discriminations over irrelevant discriminations only for adults who learned brightness categories. Thus, while we expected dimensional classifiers would show worse within-category discrimination along the irrelevant dimension and enhanced between-category discrimination, overall, we expected these results to be strongest for the brightness learners. Because it was predicted holistic classifiers would not be selectively attending to category-relevant dimensions, they should not demonstrate differences in discrimination on relevant versus irrelevant dimensions.

To examine changes in selective attention to category-relevant and irrelevant dimensions, we measured accuracy for each type of discrimination: between-category, within-category along the relevant dimension and within-category along the irrelevant dimension. Overall, children were quite accurate in discriminating stimuli: dimensional classifiers who learned brightness categories, M=.82, $t(7)$=15.71, p<.0001, dimensional classifiers who learned size categories, M=.81, $t(6)$=6.27, p<.001, holistic classifiers who learned brightness categories, M=.74, $t(6)$=5.96, p<.001, and holistic classifiers who learned size categories, M=.73, $t(4)$=5.04, p<.01, were all significantly better than chance (.50) at discriminating stimuli.

A logistic mixed regression model of effect of discrimination comparison type (between, within relevant, within irrelevant) on accuracy revealed dimensional classifiers in the brightness learning group had significantly increased accuracy for between category compared to within category discriminations on either irrelevant, or relevant dimension. They were also more accurate at within-category discriminations along relevant than irrelevant dimensions, demonstrating, overall, they were more accurate at relevant than irrelevant discriminations. However, dimensional classifiers who learned size categories were no more accurate at between-category than within-category discriminations on either irrelevant, or relevant dimensions.

Holistic classifiers are thought not to selectively attend to category relevant dimensions. Therefore, they should not show the same pattern as dimensional classifiers. However, a logistic mixed regression model showed that holistic classifiers who learned brightness categories were more accurate at between category than within category discriminations along both the irrelevant, and relevant dimension. Additionally, these children were significantly more accurate at within-category discriminations along the relevant than the irrelevant dimension, demonstrating that overall, they were more accurate at discriminating across the relevant than the irrelevant dimension. Holistic classifiers

Table 1: Results of logistic mixed regression for Category Test, Discrimination (comparing between versus within-category discriminations on the irrelevant and relevant dimensions and within-category discriminations on the relevant versus the irrelevant dimensions) and Triad Classification. z and p values/significance are reported for each model.

	Experiment 1: No Label				Experiment 2: Label				Comparison	
Classification	Dimensional		Holistic		Dimensional		Holistic		Holistic	
Task	Bright	Size	Bright	Size	Bright	Size	Bright	Size	Bright	Size
Cat. Test: Fam v Novel	.61 *ns*	.54 *ns*	1.26 *ns*	-.17 *ns*	.63 *ns*	.53 *ns*	.56 *ns*	.49 *ns*	.29 *ns*	-.12 *ns*
Discrim: b/t v w/in irrel	-3.91 *p*<.01	.25 *ns*	-2.33, *p*<.05	-.68 *ns*	-4.50 *p*<.01	1.49 *ns*	-5.29 *p*<.01	1.28 *ns*	2.25 *p*<.05	1.24 *ns*
Discrim: b/t v w/in rel	-3.84 *p*<.01	.98 *ns*	-1.93, *p*<.05	-.39 *ns*	-3.93 *p*<.01	-.42 *ns*	-4.66 *p*<.01	-.43 *ns*	2.28 *p*<.05	1.57 *ns*
Discrim: w/in rel v irrel	-3.70 *p*<.01	.70 *ns*	-2.11, *p*<.05	.01 *ns*	-4.50 *p*<.01	1.49 *ns*	-5.29 *p*<.01	1.49 *ns*	.79 *ns*	-.95 *ns*
Triad: pre v post	-.81 *ns*	-.15 *ns*	.78 *ns*	1.94 *p*<.10	-.65 *ns*	2.43 *p*<.05	2.43 *p*<.05	3.81 *p*<.01	3.34 p<.01	3.55 p<.01

learning size categories had no accuracy differences. Thus, both groups' category learning affected their discrimination abilities—but only if they learned brightness categories.

Posttest triad We next examined results of the posttest triad task. The primary question of interest is whether there was a change in the number of dimensional matches children choose from pre- to posttest. Such a change indicates learning dimensional categories—which require the learner to selectively attend to one dimension to the exclusion of another—increased children's selective dimensional attention in similarity classification. It was predicted that the dimensional classifiers would not show an increase in dimensional responding from pre to post test because they were already attending dimensionally. A logistic mixed regression model showed neither dimensional classifiers who learned brightness nor size categories were more likely to choose dimensional matches during posttest than pretest.

Holistic classifiers were also predicted to not show an increase in dimensional responding, because they were not expected to be attending dimensionally in the category-learning task. A logistic mixed regression model showed holistic classifiers who learned brightness categories had no increase in dimensional responding. However, those who learned size categories *were* marginally more likely to select dimensional matches during posttest. This suggests that perhaps these children did learn to selectively attend to size.

Conclusions Learning to categorize stimuli along a dimension increases attention to that dimension and leads to changes in discrimination. We predicted that for this to happen, the learner has to be able to attend to the relevant dimension in the first place—which holistic classifiers were not expected to do. The results of the category-learning task support this idea, demonstrating holistic classifiers were slower to learn categories organized by a single dimension. However the results of the discrimination and posttest triad tasks paint a more complicated picture. For example, holistic classifiers who learned brightness categories showed similar changes in their discrimination as the dimensional classifiers did, and holistic classifiers showed increases in dimensional responding in the posttest triad task. These results suggest that category learning on its own can facilitate dimensional attention. The critical question, then, is do labels work with category learning to boost it even more?

Experiment 2

Results of E1 suggest holistic classifiers are slower to learn categories than dimensional classifiers, but they show some increases in dimensional attention following category learning. Research shows that young children can do this in the context of novel noun generalization (Smith et al., 2002). Furthermore, we know labels facilitate category learning in adults (Lupyan et al., 2007). If labels support the development of dimensional attention more generally, then we should see a facilitative effect of labels on holistic classifiers' category learning and perhaps an even greater facilitation of their dimensional attention. In E2, we examined category learning in the context of redundant labels and assess subsequent changes in attention.

Methods

Participants 35 5-8-year-olds participated. 3 children did not complete the experiment (2 quit and 1 for equipment error), thus there were 32 children in the final group.

Procedure Methods were identical to E1, except during category learning, novel auditory category labels (leebish and grecious) were presented after feedback (the bell or buzzer) on each trial. These labels were redundant with category structure such that, for example, after each trial where a rock belonging from the ocean was presented (regardless of correct categorization) the child would hear the "leebish" Results were analyzed as in E1.

Results and discussion

Category learning As can be seen in Figure 2, a linear mixed regression model of the interaction between classifier type (holistic v. dimensional) and category structure (brightness v. size organization) on the number of blocks it took children to reach criterion revealed no effect of classifier type, *t*=.04, *NS,* nor of category structure, *t*=-.30, *NS*. Thus, labels facilitate learning of dimensional categories, such that holistic classifiers were now as quick to reach criterion as dimensional classifiers.

Category test Both groups were very accurate: dimensional classifiers who learned brightness categories, M=.84, t(6)=11.11, p<.0001, dimensional classifiers who learned size categories, M=.86, t(6)=15.16, p<.0001, holistic classifiers who learned brightness categories, M=.85, t(6)=13.32, p<.0001, and holistic classifiers who learned size categories, M=.69, t(7)=4.30, p<.01, were all significantly better than chance at categorization.

A logistic mixed regression model of trial type on categorization accuracy showed neither dimensional classifiers who learned brightness nor size categories were different in accuracy for familiar and novel stimuli. Similarly, neither holistic classifiers who learned brightness nor size categories were different in accuracy for familiar and novel stimuli. This suggests that all children may have learned something about category organization rather than about specific stimuli.

Discrimination Children were accurate in discriminating stimuli: dimensional classifiers who learned brightness categories, *M*=.83, *t(6)*=16.40, *p*<.0001, dimensional classifiers who learned size categories, *M*=.80, *t(6)*=10.90, *p*<.0001, holistic classifiers who learned brightness categories, *M*=.76, *t(6)*=7.42, *p*<.001, and holistic classifiers who learned size categories, *M*=.77, *t(7)*=6.27, *p*<.001, were all significantly better than chance.

A logistic mixed regression model of effect of discrimination type (between, within relevant, within irrelevant) on accuracy showed that dimensional classifiers in the brightness-learning group were more accurate at between category than within category discriminations for both irrelevant, and relevant dimensions. These children were also significantly more accurate at within-category discriminations along relevant than irrelevant dimensions. Dimensional classifiers who learned size categories were no more accurate at between category discriminations than at within category discriminations on either the irrelevant, or relevant dimension, nor were they more accurate at within-category discriminations along either dimension.

A logistic mixed regression model showed that holistic classifiers who learned brightness categories were more accurate at between category, compared to within category, discriminations along both the irrelevant, and relevant dimensions. However, those in size learners did not show any differences in discrimination. Thus, all children showed an effect of category learning on discrimination—but only if they learned brightness.

Posttest triad It was predicted that dimensional classifiers would not increase in dimensional responding from pre- to posttest. A logistic mixed regression model showed dimensional classifiers who learned brightness were no more likely to choose dimensional matches during the post test than on pretest. Interestingly, however, dimensional classifiers who learned size were more likely to choose dimensional matches during post test.

If labels drive attention to dimensions, holistic classifiers should show an increase in attention dimensional similarity. In fact, a logistic mixed regression model showed both holistic classifiers who learned brightness and size categories increased in dimensional responding.

Conclusions Incidental labels in a category-learning task scaffolded selective attention to dimensional similarity. Unlike in E1, holistic and dimensional classifiers are equally quick to learn the categories. Holistic classifiers have relatively weak selective attention and take longer to learn dimensional categories. Once they learn the categories, however, they show slight increases in dimensional attention—as evidenced by discrimination accuracy and increases in dimensional classification. Labels support even weak selective attention, thus when holistic classifiers learn dimensional categories in the context of *labels*, they learn the categories more quickly. This increase in selective attention cascades forward to both their discrimination abilities and classification biases. So, as Lupyan suggested in his 2008 study of category grouping on visual processing, "categories matter; named categories matter more." A direct comparison of holistic classifiers from the two experiments should clarify the extent to which performance of those in E2 is, in fact, significantly better than those in E1.

Between-experiment comparison

Category learning A linear mixed regression model of the interaction between experiment (label v. no label) and category structure (size v. brightness) on the number of blocks to reach learning criterion revealed holistic classifiers were significantly faster to reach criterion in the label than in the no label experiment, t=-26.57, p<.0001. There was an overall effect of category structure, such that children were faster to learn brightness than size categories, t=-23.66, p<.0001, however, there was also an interaction such that children in the label experiment showed less difference in speed of learning the two category types than those in the no label experiment, t=7.47, p<.0001. This is direct evidence that labels facilitate category learning in children who have difficulty attending to dimensional similarity.

Category test A mixed logistic regression model of the interaction between experiment (label versus no label) and trial type (familiar or novel) on children's categorization revealed that neither holistic classifiers who learned brightness nor size categories showed an effect of experiment. Thus, children were equally accurate at categorizing familiar and novel stimuli.

Discrimination If labels facilitate category learning because they increase children's selective attention to category-relevant dimensions, then children in the label experiment should show the biggest enhancement in accuracy for relevant over irrelevant discriminations. A logistic mixed regression model of the interaction between experiment (label v. no label) and discrimination type (between, within-relevant, or within-irrelevant) revealed that children in the label experiment showed a larger difference in accuracy in between-category discriminations relative to within-category discriminations on the relevant dimension, and relative to within-category discriminations on the irrelevant dimension. However, size learners did not show an effects of experiment. This demonstrates (for brightness learners) the presence of a label made effects of categorization on discrimination stronger. Labels increase selective attention to dimensions above and beyond category learning.

Posttest triad If word learning drives the emergence of selective attention to dimensions over development, then when labels are presented during category learning we may also see indices of these changes in attention over the course of an experiment. Therefore holistic classifiers in the label experiment should show the largest increases in dimensional responding from pre- to posttest triad task. This was supported by logistic mixed regression models of the effect of experiment (label v. no label) on change in dimensional responses from pre- to posttest triad revealing that both holistic classifiers who learned brightness and size categories had a larger increase in dimensional responding from pre- to posttest in the label experiment. The presence of a label not only immediately facilitated category learning, but also led to cascading changes in similarity classification.

Conclusions

Results of the comparison analyses demonstrate the extent to which labels support selective attention above and beyond category learning by demonstrating that holistic classifiers were significantly faster to learn in the presence of labels. Similarly, while the qualitative assessment of E1 and 2 demonstrated both groups of holistic classifiers who learned brightness categories showed the "adult" pattern found by Goldstone (1994), the comparison analysis shows that those in the label experiment demonstrate a more extreme pattern. This suggests category learning affects attention to dimensions, but *labeled* category learning affects it more. Finally, comparison of changes in dimensional responding in the triad task offers additional evidence that labels scaffold attention to dimensional similarity above and beyond category learning. The only difference between the two experiments was the presence of incidental, redundant, labels during category learning. Yet this was enough to change children's pattern of responding in an unrelated similarity classification task.

Overall, these analyses generally demonstrate that while category learning supports selective dimensional attention even in children who preferentially attend to holistic similarity, labeled category learning exaggerates this process, facilitating both category learning and attention to dimensional similarity. However, one important remaining question that needs to be addressed by future research is why category learning and labeled category learning only have these effects when the categories are organized by brightness and not size. While our results replicate Goldstone's 1994 findings with adults, it is still unclear why brightness is easier to learn and why learning brightness, but not size, should lead to differences in discrimination abilities.

Our results clearly demonstrate that labels can scaffold this attention in similarity classification, suggesting that, as in the case of early word learning biases, regularities between labels, categories, and similarity lead to selective attention to dimensions. Future research will be needed to further explore how children can eventually do this without any external linguistic support. Nevertheless, these experiments are an important first step in unifying our understanding of the attentional processes involved in early word with those in a broader context.

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