University of Plymouth

PEARL **https://pearl.plymouth.ac.uk**

Faculty of Health: Medicine, Dentistry and Human Sciences School of Psychology

2022-08

Building lexical networks: Preschoolers extract different types of information in cross-situational learning

Chen, C-H

http://hdl.handle.net/10026.1/19028

10.1016/j.jecp.2022.105430
Journal of Experimental Child Psychology
Elsevier

All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.

Building Lexical Networks: Preschoolers Extract Different Types of Information in Cross-situational Learning

Chi-hsin Chen[1] & Chen Yu[2]

[1] School of Psychology, University of Plymouth
Portland Square, Plymouth PL4 8AA, United Kingdom

[2]Department of Psychology, The University of Texas at Austin
108 E. Dean Keeton Stop A8000, Austin, Texas 78712, USA

Corresponding Author:
Chi-hsin Chen
Email: chihsin.chen.cc@gmail.com

Acknowledgements

This research was supported by grants from the National Institutes of Health (R01 HD074601 and R01 HD093792). We thank Elizabeth Fender and Nancy Goodrich for help with data collection and coding.

Abstract

Children’s everyday learning environment is semantically structured. For example, semantically related things (e.g., fork and spoon) usually co-occur in the same contexts. The current study examines the effects of semantically structured contexts on preschool-age children’s (N = 65, 33 girls, age range: 52-68 months) use of statistical information to learn novel word-object mappings. Children were assigned into one of two conditions, in which objects from the same semantic category repeatedly co-occurred in the same trials (Same-category condition) or objects from different categories repeatedly co-occurred in the same trials (Different-categories condition). Children’s word learning performance in the two conditions were comparable. However, their errors at test suggested that information extracted by children in the two conditions differed. Importantly, children in the Same-category condition extracted both statistical and semantic relationships from the stimuli.

Running head: Cross-situational learning in semantic contexts

Keywords: cross-situational learning; child word learning; semantic information; co-occurrence frequencies; error analyses

Building Lexical Networks: Preschoolers Extract Different Types of Information in Cross-situational Learning

Every time a child hears a novel word, there are usually many potential referents in view (Medina et al., 2011). Therefore, a challenge young learners face in word learning is how to solve the referential uncertainty problem (Quine, 1960). Over the past few decades, many researchers have discovered various learning mechanisms and/or processing biases that may allow young learners to pick the correct referent(s) upon hearing a novel word in the first encounter or in a few exposures (e.g., Baldwin, 1993; Carey & Bartlett, 1978; Markman & Hutchinson, 1984; Tomasello & Akhtar, 1995; Waxman & Booth, 2001). These studies have produced fruitful results and enhanced our understanding of how young children *fast map* a novel word to its referent(s). More recently, an alternative mechanism has been proposed in which learners rely on accumulating statistical information, such as word-object co-occurrences, across different learning situations and using the statistics to gradually build up word-referent mappings (e.g., Smith & Yu, 2008; Yu & Smith, 2007). Infants and young children have been shown to be able to use this type of *cross-situational statistics* to learn not only object names, but also verbs and adjectives (e.g., Akhtar & Montague, 1999; Childers & Paik, 2009; Scott & Fisher, 2012; Smith & Yu, 2008).

Most extant studies on children’s cross-situational word learning focus on their ability to use *statistical information alone* to learn the mappings between words and objects; and therefore, they use novel stimuli that have no apparent association with each other (Benitez et al., 2020; Smith & Yu, 2008; Suanda et al., 2014; Vlach & Johnson, 2013). Although these studies have demonstrated young learners’ abilities to use co-occurring statistics to build word-object mappings, the training data used in these experimental studies differ dramatically from the data that children receive in their daily environment. Things in the real world are distributed in a more structured way in that semantically related items often co-occur in the same context(s). For example, some objects, such as forks, spoons, and knifes, are usually seen in the same visual context (Sadeghi et al., 2015); and semantically related words, such as *apple*, *banana*, and *orange*, are usually heard in the same conversational context (Roy et al., 2015; Tamis-LeMonda et al., 2019). There are abundant of semantically structured contexts in children's everyday life, which contain rich information for word learning. Yet, the effect of the structured semantic information on early statistical word learning is unknown. As a first step to fill this gap, the current study aims to examine how higher-order semantic information affects young children's use of statistical information to learn novel words.

What are some potential effects of semantically structured contexts on children's statistical word learning? Using corpus analyses, Roy and colleagues (2015) analyzed high-density video and audio recordings of a single child's daily life from 9 to 24 months of age and found that words that had been experienced in more distinctive contexts (e.g., fish, blanket) were produced earlier than words experienced in less distinctive contexts (e.g., floor, head). Or to put it differently, words that only appear in a limited number of contexts (i.e., more distinctive contexts) are learned earlier than words that appear in many different contexts (i.e., less distinctive contexts). This finding indirectly suggests that semantically structured contexts may have positive effects on early word learning. More direct evidence of the positive effects of semantically structured contexts can be found in recent experimental studies with adult participants (Chen & Yu, 2017; Dautriche & Chemla, 2014). For example, Chen and Yu (2017) tested adult learners' ability to use statistical information across learning trials to learn the mappings between novel words and familiar objects (e.g., *toma*-dog, *zorch*-rabbit). In each learning trial, learners saw four objects and heard their corresponding labels presented in a random order and had to track word-object co-occurrences across trials to learn the correct word-object mappings. In one condition, the objects seen in each learning trial tended to come from the same semantic category (e.g., a dog, a cow, a rabbit, and a horse). In another condition, the learning trials tended to consist of objects from different categories (e.g., a dog, a tomato, a car, and a chair). Adult learners had better word learning performance when the learning situations were organized in a semantically structured way.

However, whether or not the same positive effects of semantically structured contexts would be found in child learners is open to question on two grounds. First, to be able to use the semantic information in word learning, one prerequisite is that learners must first identify the semantic features, such as perceptual or functional similarities, shared among objects and then incorporate this information in their word learning process (Wojcik, 2018; Wojcik & Saffran, 2013). Although previous categorization studies show that infants as young as three months of age are able to form object categories based on perceptual features of objects in just a few exposures (e.g., Quinn, Eimas & Rosenkrantz, 1993), it has also been found that, in some circumstances, even adults struggle to extract perceptual similarities among objects when their main task is to learn word-object mappings (e.g., Chen et al., 2017). Therefore, it is not clear whether child learners are able to quickly identify that co-occurring objects in a learning situation are semantically related and therefore belong to the same category while trying to infer object-word mappings. Second, and relatedly, to leverage rich information from semantically structured contexts, learners need to keep track of not only co-occurrence statistics among words and objects but also co-occurrence statistics among semantically related objects. To do so, learners need to track multiple levels of statistical regularities, keep different pieces of information in mind, and flexibly switch attention between different dimensions. These processes have all been shown to be very challenging for young children (Chi, 1978; Zelazo et al., 2003). Those attentional and computing demands suggest that the effect of semantically structured contexts may not be as beneficial as it has been observed in adult experiments. It is even possible that semantically structured contexts may hinder young children’s statistical word learning, as the additional level of structured semantic information in the learning trials may compete for attention and processing resources and lead to worse learning outcomes.

Current study

In the current study, we tested the effects of semantically structured learning contexts on four- to five-year-old children’s cross-situational word learning. We chose preschool-age children, because this is a period when word learning shows steady acceleration (Snedeker, 2009). Importantly, preschool-age children have been shown to be able to use semantic information, such as taxonomic categories including animals and tools, to sort items together (Vales et al., 2020). This suggests that they have built a (rudimentary) semantic network containing taxonomic information and are able to put this knowledge into use.

In the experiment, children were exposed to a sequence of learning trials to learn the mappings between novel objects and novel words. It is noteworthy that previous adult studies used familiar objects belonging to different categories and asked adult learners to learn novel names for those familiar objects (Chen & Yu, 2017; Dautriche & Chemla, 2014). This type of learning scenario is more similar to second language learning where learners are asked to learn novel names for objects they already have a name (or names) for. Asking children to learn novel names for novel or unfamiliar objects resembles more closely to what they experience when learning their first language.

Participants were randomly assigned into one of two conditions: Same-category condition or Different-categories condition. In the Same-category condition, most learning trials consisted of two objects from the same semantic category (e.g., two animals or two tools). In the Different-categories condition, most learning trials consisted of objects from different categories (i.e., one animal and one tool). To test the effects of semantically structured contexts on children's cross-situational word learning, we analyzed two measures at test: 1) word-object mapping accuracies and 2) types of errors. For the first measure, we compared children's word-object mapping accuracies in the Same-category and Different-categories conditions and examined whether semantically structured contexts facilitated or hindered word learning. For the second measure, we focused on two predictors of errors: semantic category membership (Chen & Yu, 2017; Dautriche & Chemla, 2014) and co-occurrence frequencies (Bunce & Scott, 2017; Suanda et al., 2014; Vouloumanos & Werker, 2009; Zettersten et al., 2018). We examined whether children were more likely to mistakenly select A) a foil object coming from the same semantic category as the target object than a foil object from a different category and/or B) a foil object that co-occurred more frequently with the target word (thus having a higher spurious correlation) than a foil object that co-occurred less frequently with the word. Finally, to have a complete picture of what types of information children extracted from the input, we examined what predicted children's object selection in a trial (regardless of correct or incorrect). We ran a statistical model that included children's response in each test trial and examined the joint effects of semantic membership and co-occurrence frequency on their responses.

Methods

Participants

Participants were 68 four- to five-year-old monolingual English-speaking children (34 girls, mean age: 58.7 months) recruited from a Midwestern town in the United States. Half of the children were randomly assigned to the Same-category condition while the other half assigned to the Different-categories condition. The data from three participants were excluded from analysis because of exhibiting a position bias (for details see the Coding section). The final sample included 65 children, with 33 children in the Same-category condition and 32 children in the Different-categories condition. Using G*Power to calculate the sensitivity of the sample size, the sample size (N = 65) has 66% power to detect an effect of d = 0.6 – an effect size equivalent to the ones found in Chen & Yu (2017) -- in a two-tailed independent-samples t-test.

Recruitment and experimental procedure were approved in advance by the University Institutional Review Board and all parents gave informed consent prior to participation. The entire sample of participants was broadly representative of the ethnicity of the state where the participants were recruited (94% European American; 3% African American; 3% Asian, Hispanic, and other), and came from a working and middle-class population.

Stimuli

The stimuli were 16 novel words, divided into two sets of eight words -- Sets A and B -- and eight pictures of real objects depicting unfamiliar animals or tools (Fig. 1). Half of the children were randomly assigned to learn the objects mapping with the words in Set A, while the other half were presented with the objects mapping with Set B. Each set of novel words contained two monosyllabic words and six disyllabic words that followed the phonological rules of English (e.g., *dax, zorch, toma, vamy*). The words were recorded by a female speaker using child-directed speech.

Four pictures of unfamiliar animals and four of unfamiliar tools were used (Fig. 1). According to adults' rating of age-of-acquisition, all names for the objects are typically learned after 8 years of age (Kuperman et al., 2012). Even though adults sometimes over-estimate their exact age of acquisition of different words, their ratings, nonetheless, correlate with children's learning of those words (Brysbaert, 2017). Words with higher ratings tend to be learned later. Using the rating of age-of-acquisition as a guideline, these objects should be unfamiliar to preschoolers.

Figure 1

Stimuli

Note. The visual stimuli used in the experiment were eight objects unfamiliar to preschool-age children. Four objects belong to the category of animals and four belong to the category of tools.

Design and Procedure

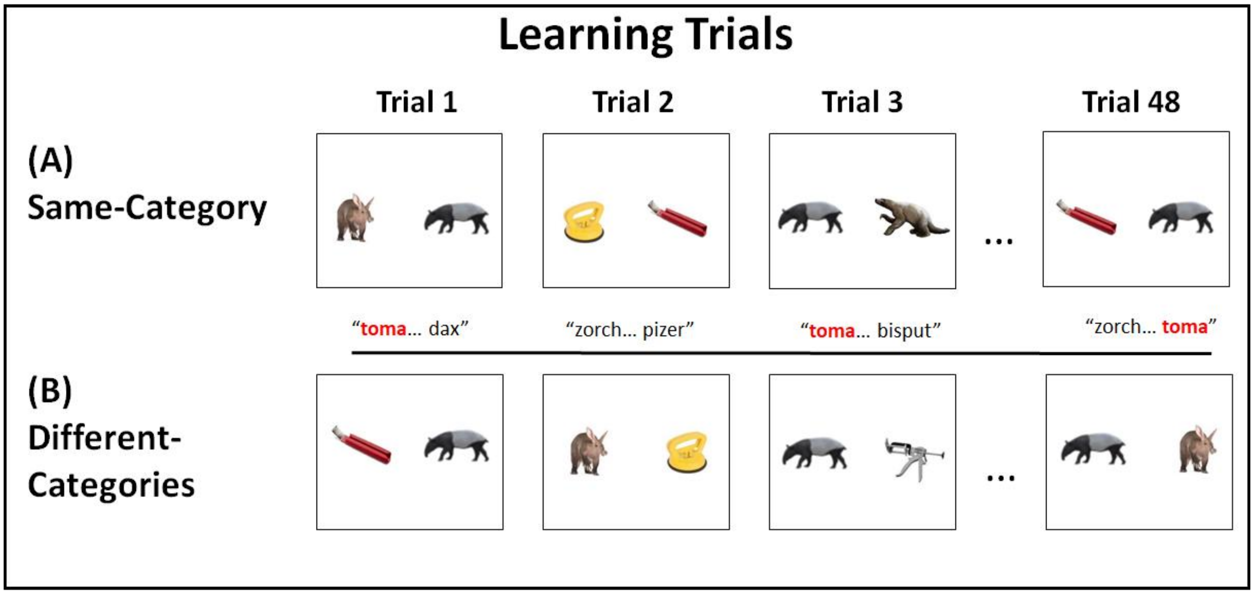
Prior to the experiment, children were led to the experiment room and sat approximately 3.5 feet (1 meter) in front of a 17-inch screen. An experimenter adjusted the height of the screen to the child's eye level and the distance of their chair so that the screen was within their reach. A camcorder was placed over children's shoulder to record both the screen and their pointing gestures or touching of the screen. Children were introduced to a dinosaur puppet Bobo and told to help Bobo find some pictures. They were instructed to point to a picture on the screen that matched with the word they heard. They went through three practice trials, where they heard one familiar word (e.g., bus) and had to pick its referent from four familiar objects (e.g., a bus, a dog, a shirt, and a flower). Children were encouraged to make one and only one choice during this session.

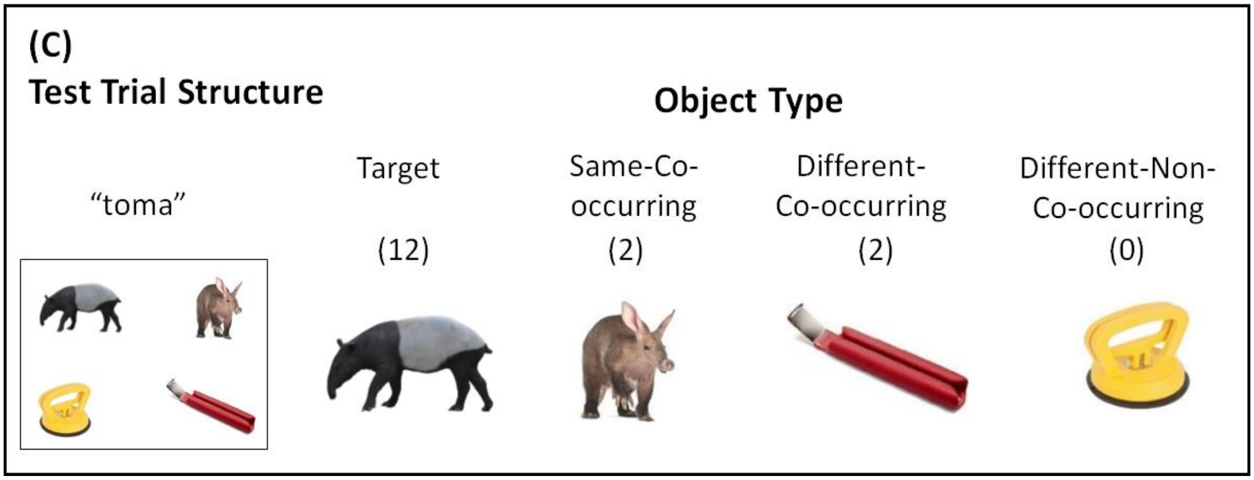
After going through three practice trials with familiar objects, children were informed that they were going to watch a video and learn a few new words in Bobo's language. They were instructed to pay attention and learn which word went with which object by the end of the video presentation.

Children were randomly assigned to one of two conditions: Same-category condition or Different-categories condition. In each condition, children went through 48 learning trials, each lasting six seconds. In each trial, children saw two objects and heard two novel words presented in a random order (Fig. 2A & 2B). Within each trial, children were not given the information of which word was mapped to which object. However, as can be seen from Fig. 2, every time they heard a word (e.g., *toma*), its referent (e.g., Malayan tapir) was always present in the trial. As long as children kept track of the word-object co-occurrences across trials, they should be able to learn the correct word-object mappings. Across trials, children saw each object and heard its name 12 times. In between every six trials, children saw a Sesame Street character and heard a phrase that encouraged them to keep paying attention (e.g., "Wow, look!" "Look at this!").

Figure 2

Learning and Testing Trials





Note. Children went through 48 learning trials in each condition. In each trial, they saw two objects and heard two words presented in a random order. Children had to track the word-object co-occurrences to learn the correct word-object mappings. (A) In the Same-category condition, 32 trials had two objects from the same category and 16 trials had two objects from different categories. (B) In the Different-categories condition, 32 trials had two objects from different categories and 16 trials had the objects from the same category. (C) In each test trial, children heard a word and had to pick its referent from four objects. The four objects consisted of a target, a Same-Co-occurring foil, a Different-Co-occurring foil, and a Different-Non-Co-occurring foil.

The numbers in the parentheses indicate the co-occurrence frequencies between the test word and the objects during the learning session. The target object co-occurred with the word 12 times during the learning session. The Same-Co-occurring foil and the Different-Co-occurring foil both co-occurred with the word twice. The Different-Non-Co-occurring foil never co-occurred with the word during the learning session.

In the Same-category condition, of the 12 occurrences, each object co-occurred with other members from the same category in eight trials and with the objects from the other category in four trials. Because of this design, 32 of the 48 learning trials contained two objects from the same category (Fig. 2A) and 16 of the learning trials had one object from the animal category and the other from the tool category. In the Different-categories condition, of the 12 occurrences, each object co-occurred with the objects from the other category eight times and with other members from the same category four times (Fig. 2B). Therefore, in the Different-categories condition, 32 learning trials had the two objects from different categories and 16 trials had the objects from the same category. The association matrices used in the Same-category and Different-categories conditions can be found in the Supplementary Materials section. Two trial lists were used in each condition. In one list, the same object never occurred in two consecutive trials. In another list, four randomly-selected objects, two from each category, occurred in two consecutive trials once, and the other four never occurred in two consecutive trials. These two trial lists did not yield in different learning results. Therefore, in the following analyses, the data from the two trial lists were combined.

After the learning trials, children were tested on how well they had learned the word-object mappings. In each test trial, children heard one word (e.g., *toma*) and were asked to pick its referent from four objects, two from each category. These four objects consisted of the target, a same-category foil, and two different-category foils (Fig. 2C). The same-category foil object co-occurred with the word twice during the learning session[1] (subsequently termed Same-Co-occurring foil). One of the different-category foils also co-occurred with the word twice during the learning session (subsequently termed Different-Co-occurring foil) while the other foil object never co-occurred with the word during the learning trials (subsequently termed Different-Non-Co-occurring foil). This design allowed us to examine whether category membership and/or co-occurrence frequencies can predict selection errors when children picked an incorrect referent in a trial. The position of the target object on the screen was counterbalanced across trials. There was a total of eight test trials, one for each to-be-learned word. A test trial was designed to end in one of two ways: 1) once an experimenter determined that the child had responded, or 2) after 20 seconds had passed without any response. Likely due to the pre-experiment practice session, all children were able to make (at least) a response for each trial within the 20-second window.

Coding

A trained coder naïve to the conditions and word-object mappings watched the videos of the testing session and coded the position of the child's selection using their pointing gesture or

---

[1] By design, the same-category member that co-occurred with the target word four times during the learning phase was not selected, because we wanted to match the co-occurrence frequencies of the same-category foil with one of the different-category foils. Since none of the different-category objects co-occurred with a target word more than twice in the Same-category condition (and vice versa, none of the same-category objects co-occurred with a target word more than twice in the Different-categories condition), we selected a same-category object that co-occurred with the target word twice as a foil, instead of the same-category object that co-occurred with the word four times.

touching of the object on the screen. A second coder coded the object selection videos for 50% of the children. The inter-coder reliability was 100%.

One child made two selections in one of the test trials. This trial was excluded from the following analyses. Three other children (one in the Same-category condition and two in the Different-categories condition) showed a position bias in their selection by pointing or touching the same position in seven or more of the eight test trials. Their data were also excluded from the analyses.

Results

All the statistical analyses reported in the following were conducted using SPSS version 25. The data and SPSS analyses scripts can be found at the Open Science Framework (OSF) site https://osf.io/gsu94/.

As we used two different sets of words (Sets A and B), we first checked whether these two word sets resulted in different learning performance (i.e., accuracy) within each condition. The two different word sets did not affect children's accuracy in the Same-category ($t(31) = .60, p = .55$) or Different-categories ($t(30) = .71, p = .48$) conditions. Therefore, the two word sets were combined in the following analyses.

To assess the effects of semantically structured contexts on children's statistical word learning, we used two measures: word-object mapping accuracies and children's error patterns in the test trials. In the following, we first analyze the accuracies in word-object mappings in the Same-category and Different-categories conditions. We then focus on the errors children made and examine whether semantic category membership and/or co-occurrence frequencies predicted their errors. Finally, to examine whether children were able to extract multiple types of information from the stimuli, we included all responses (both correct and incorrect) and examined the effects of semantic information and statistical regularities on their overall responses. In the following analyses, we used Generalized Estimating Equations (GEE) to account for the non-independence and non-normal distributions of the data (Liang & Zeger, 1986)[2].

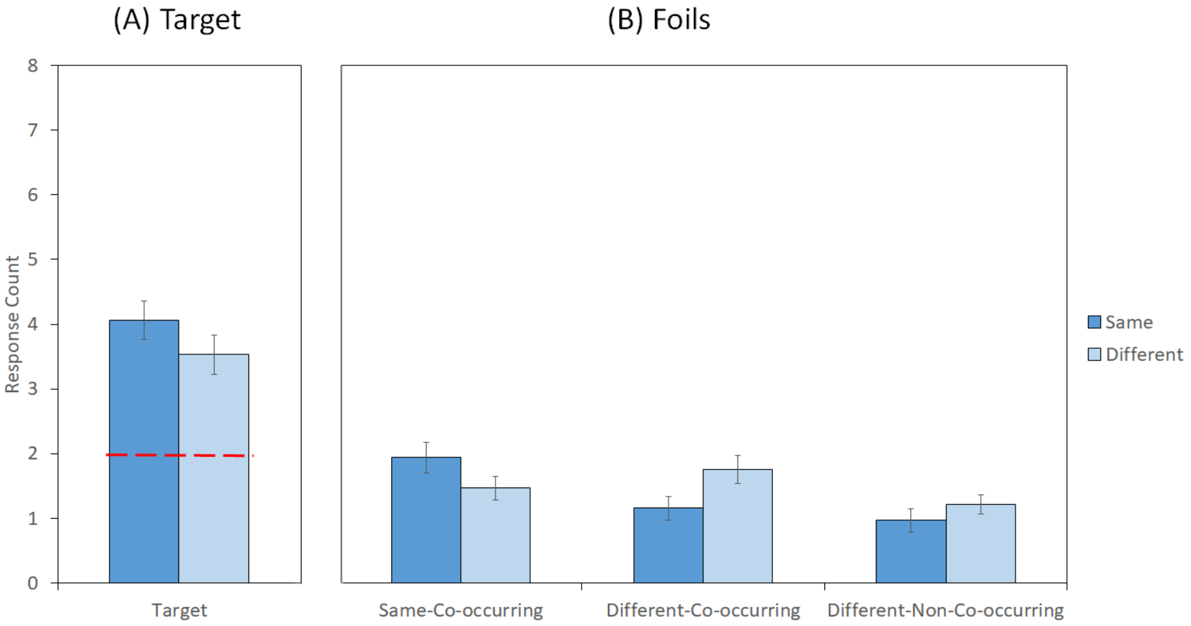
We first checked whether children were able to learn correct word-object mappings by comparing children's accuracies, as measured by their target selection counts in the eight test trials, against the chance level (i.e., 2 out of 8, as the chance of randomly picking the target in each test trial was 1/4). In this set of analyses, as the dependent measure was target selection count, we used a negative binomial link function. On average, children in both conditions had a higher accuracy than expected by chance (Fig. 3A; Same: $M = 4.06$, $SD = 1.73$, Wald $\chi^2 = 67.12$, $p < .001$; Different: $M = 3.53$, $SD = 1.72$, Wald $\chi 2 = 75.69$, $p < .001$). There was no significant difference in children's word-object mapping accuracies in the two conditions, Wald $\chi^2 = 1.58$, $p = .21$. These results suggest that children were able to learn word-object mappings in both conditions and the semantic structured contexts did not have a significant positive or negative effect on their statistical word learning accuracies.

Figure 3

Count of different types of responses

---

[2] GEE models are population-averaged models and do not aim to provide subject- or item-specific estimates (Hu et al., 1998; Liang & Zeger, 1986). Instead of modeling by-subject or by-item effects, GEE models account for dependency between repeated measurements by using "working correlation matrices" to estimate the variances of the regression coefficients (Hanley et al., 2003). The models calculated within-cluster correlations and then used the correlations to estimate regression parameters and calculated standard errors.



Note. (A) Children's target selection count (i.e., accuracy) in the eight test trials in the Same-category and Different-categories conditions. The red dashed line indicates chance level. The error bars represent standard errors (SE). (B) Children's average response count (and SE) of each foil type (Same-Co-occurring foil, Different-Co-occurring foil, and Different-Non-Co-occurring foil) in the Same-category and Different-categories conditions.

We then zoomed into the trials in which children made an incorrect selection and examined which foil object they chose. Two children (one in the Same-category condition and the other in the Different-categories condition) did not make any errors at test; and therefore, their data were not included in the error analyses. We first examined whether children in the two conditions made different types of errors by using Condition (Same-category vs. Different-categories) and Object type (Same-Co-occurring foil, Different-Co-occurring foil, and Different-Non-Co-occurring foil) as the predictors and response count as the dependent variable (Fig. 3B). Again, as the dependent measure was response count, we used a negative binomial link function. There was a significant interaction between Condition and Object type, Wald $\chi 2$ = 8.45, p = .015. This interaction indicates that children in these two conditions tended to select different types of foils when they made an error. Moreover, there was a significant object type effect, Wald χ^2 = 11.33, p = .003, suggesting that children preferred certain foil type(s) over others. To further examine what drove error selection in each condition, we used category membership and co-occurrence frequencies of each foil object as the predictors and whether or not a foil object was selected as the dependent measure. In this set of analyses, we used a binary logistic link function. We found that category membership was a significant predictor of errors in the Same-category condition, Wald χ^2 = 6.29, p = .012, while co-occurrence frequencies did not predict errors, Wald χ^2 = 0.37, p = .54. In contrast, in the Different-categories condition, the effect of co-occurrence frequencies was close to the margin of statistical significance, Wald χ^2 = 3.76, p = .052, while there was no effect of category membership, Wald χ^2 = 1.01, p = .32. The error analyses suggest that children in the two conditions made different types of errors. Children trained in the Same-category condition were more likely to mistakenly select a foil from the same category as the target object. In contrast, even though the statistical result did not reach the significance level of $p < .05$, there was a trend that children trained in the Different-categories condition mistakenly selected a foil based on its co-occurrence frequency.

The analyses presented above focused on either children's target selection *or* errors. Finally, to answer the question of whether children were able to extract multiple levels of information from the stimuli, we included all responses (both correct and incorrect) and used two factors -- a semantic factor, as determined by the category membership of an object (target category vs. non-target category) and a statistical factor, as measured by how often an object co-occurred with a word during learning – to predict children's choice in each test trial. Because the dependent measure was whether or not an object was selected in a trial, we used a binary logistic function in the following analyses. In the Same-category condition, both semantic and statistical factors were significant predictors of children's choices (Semantic: Wald χ^2 = 8.52, p = .004; Statistical: Wald χ^2 = 17.16, p < .001). In contrast, the only significant predictor of children's choices in the Different-categories condition was the statistical factor (Semantic: Wald χ^2 = 0.64, p = .43; Statistical: Wald χ^2 = 23.01, p < .001). Together, these results suggest that children in the Same-category condition extracted both semantic information and statistical regularities from the stimuli and used them at test. In contrast, children in the Different-categories condition mainly relied on statistical regularities to make their responses.

Discussion

In this study, we investigated the effect of semantically-structured contexts on preschool-age children's statistical word learning. Children were assigned to one of two conditions: Same-category condition or Different-categories condition. Children had comparable word learning performance in the two learning conditions. However, their response patterns suggest that they paid attention to different types of information in the two conditions.

Learning Word-object Mappings

Previous adult cross-situational learning studies have shown that semantically structured contexts facilitated adults' learning of novel words (Chen & Yu, 2017; Dautriche & Chemla, 2014). However, in the current study, we did not find any significant difference in children's word learning accuracies between the Same-category and Different-categories conditions, even though the accurate response mean was numerically higher in the former condition. There are multiple possible explanations for why there was no significant semantic effect in children's word learning accuracies. Some explanations are more theoretically-related while others are methodologically-related. We will start with theoretically-related explanations. First, likely due to children's (limited) information processing and memory capacity (Bjorklund et al., 1992; Cerella & Hale, 1994; Kail, 2000; Murphy et al., 2003), the beneficial effects of semantic information may not be strong enough to boost their word learning performance to a level that is much greater than in the Different-categories condition. It is possible that with the increase of information processing or memory capacity, there will be a stronger semantic context effect in older children's statistical word learning. Second, another separate, but related, factor is children's gist or theme extraction ability and their knowledge base (Bjorklund, 1987; Brainerd et al., 2008; Howe et al., 2009). Preschool-age children's gist and theme extraction abilities from visual and linguistic input and their knowledge of semantic categories (i.e., animals and tools) are still developing. Therefore, compared to adult learners, it is likely a lot more effortful for them to put the semantically structured contexts to use (Frankel & Howard, 1985; Murphy et al., 2003). One possible future direction is to study how children's prior knowledge and theme extraction ability affect their use of semantic information in statistical word learning (see Jenkins et al., 2015). Third, semantically structured contexts may have created *both* positive and negative effects in children's statistical word learning and these effects cancelled out. Even though the semantically structured contexts may help children organize and remember the objects they saw during the learning phase, the perceptual or feature similarities among objects in the same category may make same-category objects more competitive foils than different-category objects (Callaghan, 2000; Cohen et al., 2014). Therefore, the knowledge accumulated from the semantically structured contexts during learning may create a negative effect at test.

With regard to methodologically-related explanations, first, only 32 out of the 48 learning trials (66.7%) had both objects from the same category in the Same-category condition. The manipulation of semantic coherence was only probabilistic and may not be strong enough. Another possible direction for future study is to test whether having a stronger manipulation of semantic coherence will create a stronger semantic effect. Second, and relatedly, in the Same-category condition of our study, the learning trials alternated randomly between different semantically structured contexts or categories. That is, children could see one animal-themed trial followed by one tool-themed trial, which in turn was followed by another animal-themed trial. However, in real-life scenarios, one semantically structured context is usually associated with an activity or some related activities, which can last from minutes to hours. For example, children may see food items in a dining context before moving on to see toy animals in a play context -- each of these contexts could last a while. This type of scenario may be better captured with a blocked design, which has been shown to affect adults' and children's word and category learning (Carvalho & Goldstone, 2015; Chen et al., 2018; Vlach et al., 2008; Vlach & Johnson, 2013). A blocked design can potentially highlight the similarities across trials and facilitate children's extraction of semantic information. And finally, there are dramatic changes in attention, memory, and information processing abilities during childhood and adolescence (D. F. Bjorklund et al., 1992; Cerella & Hale, 1994; Kail, 2000; Murphy et al., 2003). Even with the exact same paradigm, certain effects (e.g., spacing) seen in adults may not be found in children (Benitez et al., 2020). Therefore, adult learners' performance may not be a good model to predict child performance.

Building Lexical Networks

Children’s response patterns at test suggest that they extracted multiple types of information from the learning trials. At first glance, in the Same-category condition, the findings from the error analyses seem to be inconsistent with the final set of analyses that included all responses. In the error analyses, only semantic category membership was a significant predictor while the statistical factor (i.e., co-occurrence between a word and a foil object) did not predict children’s error selection in a trial. In contrast, the final set of analyses suggest that both semantic and statistical factors were significant predictors of children’s object selection. This was because the last set of analyses included both target responses and error responses. As the accuracy analyses showed, children in both conditions performed significantly above chance in mapping words to their target referents. To successfully do that, they had to track word-object co-occurrence statistics across trials. Therefore, when we included both target and error responses in the final set of analyses, both semantic and statistical factors were significant predictors of children’s performance.

To our knowledge, our study provides the first evidence that preschool-age children are able to simultaneously extract semantic relations and statistical regularities among co-occurring objects across different learning events. In addition to word-object mappings, children in the Same-category condition learned that objects tended to co-occur with members from the same category and therefore were more likely to select a same-category foil than different-category foils. This pattern is consistent with previous studies on adults' cross-situational word learning (Chen & Yu, 2017; Dautriche & Chemla, 2014; Zettersten et al., 2018) and indicates developmental continuity in statistical word learning. Even though this semantic information may not be strong enough to boost children’s word learning performance above the level of using co-occurrence frequencies alone, it is strong enough to influence their error patterns at retrieval -- a finding consistent with previous studies on young children’s naming errors (McGregor, Friedman, Reilly, & Newman, 2002). On the other hand, the responses made by the children in the Different-categories condition indicate that they noticed the co-occurrence frequencies between words and objects and were able to use this information to successfully learn word-object mappings. This finding is consistent with previous adult, child, and infant studies showing that learners are sensitive to the statistics in the input (Bunce & Scott, 2017; Roembke & McMurray, 2016; Suanda et al., 2014; Vouloumanos & Werker, 2009; Zettersten et al., 2018). Even though co-occurrence frequency was not a significant predictor of children’s errors in the Different-categories condition, a marginal effect at $p = .052$ suggest that it may be worth future investigation. Taken together, these results suggest that 1) preschool-age children are capable of tracking different kinds of regularities in cross-situational learning; 2) they flexibly allocate attention and processing resources based on what kinds of regularities are available in the environment; and 3) the learning contexts affect what children pay attention to and what they learn.

Finally, from our current study, it is not clear whether young children integrated the newly learned items into the (relatively well-established) animal versus tool categories in their existing sematic network (Vales et al., 2020), or whether they formed temporary place-holding animal-like versus tool-like categories during the learning process and then used this rudimentary categorical information at test. It is likely that different individuals used different processes in their learning. Nonetheless, the response patterns in the two experimental conditions of the current study suggest that children did not just track the mapping between one word and one object at a time, as suggested by some previous studies (Medina et al., 2011; Trueswell et al., 2013). Instead, they tracked the co-occurrences across many word-object pairings and at the same time extracted the similarities among items and integrated this information into a network of semantically or statistically related items. That is, in addition to forming word-object mappings, they built object-object associations and learned the semantic relationships among items. This type of learning is more in line with either a global associative learning account (e.g., Yu & Smith, 2007), which tracks multiple associations within and across contexts, or a more recent local learning account, Pursuit, which combines an associative learning mechanism with a hypothesis-testing component (Stevens et al., 2017). These types of models are able to track multiple associations and use contextual information at test. They can explain why Same-Co-occurring foils were competitive at test in the Same-category condition. Tracking multiple statistics simultaneously is likely one pathway contributing to children's building of lexico-semantic networks (Wojcik, 2018; Wojcik & Saffran, 2013).

Conclusions

Everyday learning environments consist of rich semantic information, in that objects and words that are semantically related tended to co-occur in the same contexts. In this study, we investigated the effects of semantically structured contexts on children's statistical word learning. Our study provides the first evidence of preschool-age children's ability to extract both semantic and statistical information from semantically structured word learning contexts. The results shed lights on our understanding of how children build up lexical networks.

References

Akhtar, N., & Montague, L. (1999). Early lexical acquisition: The role of cross-situational learning. *First Language*, *19*(57), 347–358.

Baldwin, D. A. (1993). Infants' ability to consult the speaker for clues to word reference. *Journal of Child Language, 20*(2), 395–418.

Benitez, V. L., Zetterman, M., & Wojcik, E. (2020). The temporal structure of naming events differentially affects children's and adults' cross-situational word learning. *Journal of Experimental Child Psychology*, *200*, 104961.

Bjorklund, D. (1987). How age changes in knowledge base contribute to the development of children's memory: An interpretive review. *Developmental Review*, *7*(2), 93–130.

Bjorklund, D. F., Coyle, T. R., & Gaultney, J. F. (1992). Developmental differences in the acquisition and maintenance of an organizational strategy: Evidence for the utilization deficiency hypothesis. *Journal of Experimental Child Psychology, 54*(3), 434–448.

Brainerd, C. J., Reyna, V. F., & Ceci, S. J. (2008). Developmental reversals in false memory: A review of data and theory. *Psychological Bulletin*, *134*(3), 343–382.

Brysbaert, M. (2017). Age of acquisition ratings score better on criterion validity than frequency trajectory or ratings "corrected" for frequency. *Quarterly Journal of Experimental Psychology*, *70*(7), 1129–1139.

Bunce, J. P., & Scott, R. M. (2017). Finding meaning in a noisy world: Exploring the effects of referential ambiguity and competition on 2·5-year-olds' cross-situational word learning. *Journal of Child Language*, *44*(3), 650–676.

Callaghan, T. C. (2000). Factors affecting children's graphic symbol use in the third year: Language, similarity, and iconicity. *Cognitive Development*, *15*(2), 185–214.

Carey, S., & Bartlett, E. (1978). Acquiring a single new word. *Child Language Development*, *15*, 17–29.

Carvalho, P. F., & Goldstone, R. L. (2015). The benefits of interleaved and blocked study: Different tasks benefit from different schedules of study. *Psychonomic Bulletin & Review, 22*(1), 281–288.

Cerella, J., & Hale, S. (1994). The rise and fall in information-processing rates over the life span. *Acta Psychologica*, *86*(2–3), 109–197.

Chen, C., & Yu, C. (2017). Grounding statistical learning in context: The effects of learning and retrieval contexts on cross-situational word learning. *Psychonomic Bulletin & Review*, *24*, 920–926.

Chen, C., Zhang, Y., & Yu, C. (2018). Learning object names at different hierarchical levels using cross-situational statistics. *Cognitive Science*, *42*(S2), 591–605.

Chi, M. T. (1978). Knowledge structures and memory development. In *Children's thinking: What develops?* (pp. 73–96). Erlbaum.

Childers, J. B., & Paik, J. H. (2009). Korean-and English-speaking children use cross-situational information to learn novel predicate terms. *Journal of Child Language*, *36*(1), 201–224.

Cohen, M. A., Konkle, T., Rhee, J. Y., Nakayama, K., & Alvarez, G. A. (2014). Processing multiple visual objects is limited by overlap in neural channels. *Proceedings of the National Academy of Sciences*, *11*(24), 8955–8960.

Dautriche, I., & Chemla, E. (2014). Cross-situational word learning in the right situations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(3), 892–903.

Frankel, M., & Howard, A. R. J. (1985). Associative and categorical hypotheses of organization in the free recall of adults and children. *Journal of Experimental Child Psychology*, *40*(2), 304–318.

Hanley, J. A., Negassa, A., Edwardes, M. D. D., & Forrester, J. E. (2003). Statistical analysis of correlated data using generalized estimating equations: An orientation. *American Journal of Epidemiology*, *157*(4), 364–375.

Howe, M. L., Wimmer, M. C., & Blease, K. (2009). The role of associative strength in children's false memory illusions. *Memory*, *17*(1), 8–16.

Hu, F. B., Goldberg, J., Hedeker, D., Flay, B. R., & Pentz, M. A. (1998). Comparison of population-averaged and subject-specific approaches for analyzing repeated binary outcomes. *American Journal of Epidemiology*, *147*(7), 694–703.

Jenkins, G. W., Samuelson, L. K., Smith, J. R., & Spencer, J. P. (2015). Non-Bayesian noun generalization in 3-to 5-year-old children: Probing the role of prior knowledge in the suspicious coincidence effect. *Cognitive Science*, *39*(2), 268–306.

Kail, R. (2000). Speed of Information Processing: Developmental Change and Links to Intelligence. *Journal of School Psychology*, *38*(1), 51–61.

Kuperman, V., Stadthagen-Gonzalez, H., & Brysbaert, M. (2012). Age-of-acquisition ratings for 30,000 English words. *Behavior Research Methods*, *44*, 978–990.

Liang, K. Y., & Zeger, S. L. (1986). Longitudinal data analysis using generalized linear models. *Biometrika*, *73*(1), 13–22.

Markman, E. M., & Hutchinson, J. E. (1984). Children's sensitivity to constraints on word meaning: Taxonomic versus thematic relations. *Cognitive Psychology*, *16*(1), 1–27.

Medina, T. N., Snedeker, J., Trueswell, J. C., & Gleitman, L. R. (2011). How words can and cannot be learned by observation. *Proceedings of the National Academy of Sciences*, *108*(22), 9014–9019.

Murphy, K., McKone, E., & Slee, J. (2003). Dissociations between implicit and explicit memory in children: The role of strategic processing and the knowledge base. *Journal of Experimental Child Psychology*, *84*(2), 124–165.

Quine, W. V. O. (1960). *Word and object*. Cambridge, MA: MIT Press.

Roembke, T. C., & McMurray, B. (2016). Observational word learning: Beyond propose-but-verify and associative bean counting. *Journal of Memory and Language*, *87*, 105–127.

Roy, B. C., Frank, M. C., DeCamp, P., Miller, M., & Roy, D. (2015). Predicting the birth of a spoken word. *Proceedings of the National Academy of Sciences*, *112*(41), 12663–12668.

Scott, R. M., & Fisher, C. (2012). 2.5-year-olds use cross-situational consistency to learn verbs under referential uncertainty. *Cognition*, *122*(2), 163–180.

Smith, L., & Yu, C. (2008). Infants rapidly learn word-referent mappings via cross-situational statistics. *Cognition*, *106*(3), 1558–1568.

Snedeker, J. (2009). Word Learning. In *Encyclopedia of Neuroscience* (pp. 503–508). Elsevier.

Stevens, J. S., Gleitman, L. R., Trueswell, J. C., & Yang, C. (2017). The pursuit of word meanings. *Cognitive Science, 41*, 638–676.

Suanda, S. H., Mugwanya, N., & Namy, L. L. (2014). Cross-situational statistical word learning in young children. *Journal of Experimental Child Psychology*, *126*, 395–411.

Tamis-LeMonda, C. S., Custode, S., Kuchirko, Y., Escobar, K., & Lo, T. (2019). Routine language: Speech directed to infants during home activities. *Child Development*, *90*(6), 2135–2152.

Tomasello, M., & Akhtar, N. (1995). Two-year-olds use pragmatic cues to differentiate reference to objects and actions. *Cognitive Development*, *10*(2), 201–224.

Trueswell, J. C., Medina, T. N., Hafri, A., & Gleitman, L. R. (2013). Propose but verify: Fast mapping meets cross-situational word learning. *Cognitive Psychology, 66*(1), 126–156.

Vales, C., Stevens, P., & Fisher, A. V. (2020). Lumping and splitting: Developmental changes in the structure of children's semantic networks. *Journal of Experimental Child Psychology, 199*, 104914.

Vlach, H. A., & Johnson, S. P. (2013). Memory constraints on infants' cross-situational statistical learning. *Cognition*, *127*(3), 375–382.

Vlach, H. A., Sandhofer, C. M., & Kornell, N. (2008). The spacing effect in children's memory and category induction. *Cognition*, *109*(1), 163–167.

Vouloumanos, A., & Werker, J. F. (2009). Infants' learning of novel words in a stochastic environment. *Developmental Psychology*, *45*(6), 1611–1617.

Waxman, S. R., & Booth, A. E. (2001). Seeing pink elephants: Fourteen-month-olds' interpretations of novel nouns and adjectives. *Cognitive Psychology*, *43*(3), 217–242.

Wojcik, E. (2018). The development of lexical–semantic networks in infants and toddlers. *Child Development Perspective, 12*(1), 34–38.

Wojcik, E., & Saffran, J. R. (2013). The ontogeny of lexical networks: Toddlers encode the relationships among referents when learning novel words. *Psychological Science*, *24*(10), 1898–1905.

Yu, C., & Smith, L. B. (2007). Rapid word learning under uncertainty via cross-situational statistics. *Psychological Science*, *18*(5), 414–420.

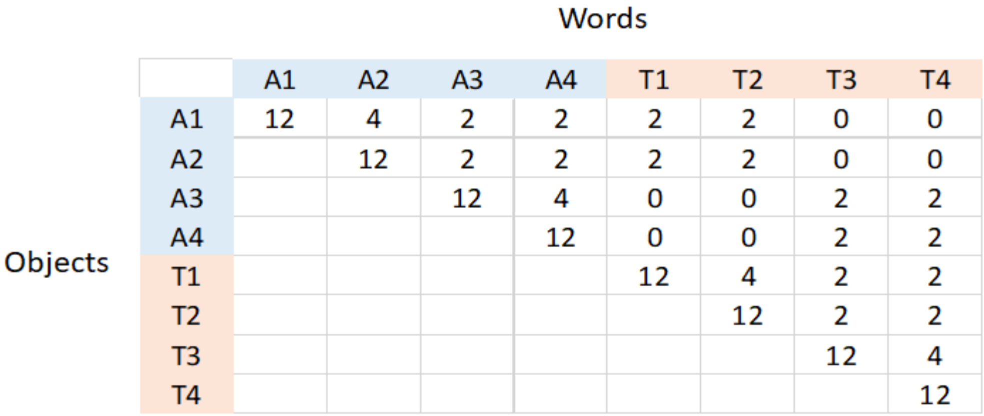
Zelazo, P. D., Muller, U., Frye, D., & Marcovitch, S. (2003). The development of executive function in early childhood: I. The development of executive function. *Monographs of the Society for Research in Child Development*, *68*(3), 11–27.

Zettersten, M., Wojcik, E., Benitez, V. L., & Saffran, J. (2018). The company objects keep: Linking referents together during cross-situational word learning. *Journal of Memory and Language*, *99*, 62–73.

Supplementary Materials

(A) Word-object association matrix in the Same-category condition and (B) word-object association matrix in the Different-categories condition. Items in the animal category: A1-A4. Items in the tool category: T1-T4. The association matrix in the Different-categories condition is matched to the matrix in the Same-category condition, with the items shuffled in the Different-categories condition.

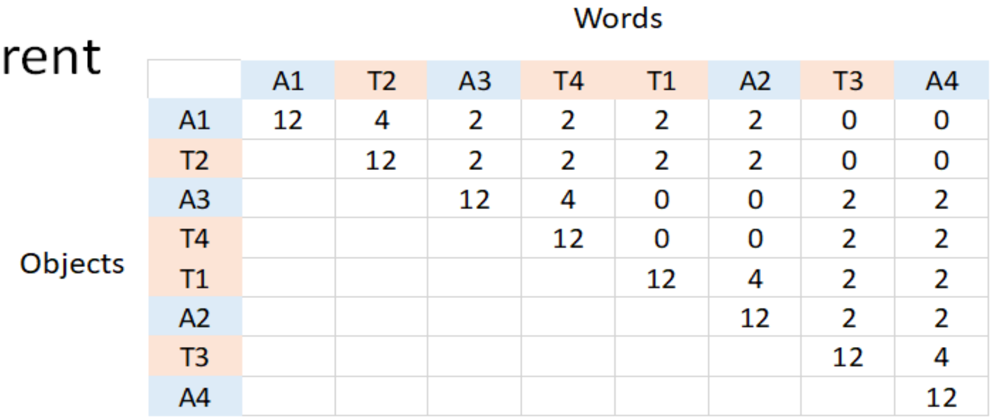
(A) Same


Words

Objects

	A1	A2	A3	A4	T1	T2	T3	T4
A1	12	4	2	2	2	2	0	0
A2		12	2	2	2	2	0	0
A3			12	4	0	0	2	2
A4				12	0	0	2	2
T1					12	4	2	2
T2						12	2	2
T3							12	4
T4								12

(B) Different


Words

Objects

	A1	T2	A3	T4	T1	A2	T3	A4
A1	12	4	2	2	2	2	0	0
T2		12	2	2	2	2	0	0
A3			12	4	0	0	2	2
T4				12	0	0	2	2
T1					12	4	2	2
A2						12	2	2
T3							12	4
A4								12