Title
Becoming Organized: How Simple Learning Mechanisms may Shape theDevelopment of Rich Semantic Knowledge

Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 42(0)

Authors
Savic, Olivera
Unger, Layla
Sloutsky, Vladimir

Publication Date
2020

Peer reviewed

Becoming Organized: How Simple Learning Mechanisms may Shape the Development of Rich Semantic Knowledge

Olivera Savic (savic.7@osu.edu)
Department of Psychology, 1835 Neil Avenue,
Columbus, OH 43210, United States

Layla Unger (unger.114@osu.edu)
Department of Psychology, 1835 Neil Avenue,
Columbus, OH 43210, United States

Vladimir Sloutsky (sloutsky.1@osu.edu)
Department of Psychology, 1835 Neil Avenue,
Columbus, OH 43210, United States

Abstract

With development, we acquire rich body of knowledge about the world in which concepts denoted by words (e.g., *juicy, apple,* and *pear*) are connected by meaningful, semantic links (e.g., *apples* and *pears* are similar, and can both be *juicy*). One potentially powerful driver of this development is sensitivity to regularities with which words co-occur in language. Specifically, language is rich regularities that can support: (1) Associative semantic links between words that *directly* co-occur together (e.g., *juicy-apple*), and (2) Taxonomic semantic links between words similar in meaning that share patterns of direct co-occurrence (e.g., *apple* and *pear* both co-occur with *juicy*). Here, we investigated the development of abilities to form semantic links from these regularities. Results revealed that both children and adults formed direct co-occurrence-based links, whereas only adults formed shared co-occurrence based links. We discuss how these results may provide key insight into how semantic organization develops.

Keywords: semantic organization; co-occurrence regularities; taxonomic development

Introduction

Our knowledge about the world is not simply a repository of stored information. Instead, it functions as an *organized semantic network,* in which concepts, denoted by words, are linked by semantic relations (Cree & Armstrong, 2012; Jones, Willits, & Dennis, 2015; McClelland & Rogers, 2003). It is difficult to overestimate the importance of semantic organization, as it supports a myriad of knowledge-dependent functions. For example, when going on a hiking trip, our knowledge of concepts linked to *hiking* can help us *retrieve knowledge about*, *discuss*, and *plan* what to bring, such as a *tent*, *backpack* and *boots*, even if we have never hiked before.

It is hardly controversial that word knowledge becomes organized with development, and that experiences acquired during development are important for driving this process (Bjorklund, 1987; for recent discussion and evidence, see Coley, 2012; Unger & Fisher, 2019). What remains less clear is *what* elements of experience drive semantic organization development, and *how*.

Here, we first provide an overview of the development of semantic organization, then propose that a key driver of this development is the formation of semantic links from statistical regularities of word use in language. Finally, we present a series of experiments investigating how abilities to form semantic links from such regularities develop.

Two Critical Types of Semantic Relations: Associative and Taxonomic

Extensive evidence suggest that, from early development into adulthood, semantic organization is shaped by *associative* links between concepts whose labels or real-world counterparts occur together in the same utterances or contexts, such as *zoo* and *animal* (Blaye, Bernard-Peyron, Paour, & Bonthoux, 2006; Fenson, Vella, & Kennedy, 1989; Lin & Murphy, 2001; Unger, Savic, & Sloutsky, In Press; Walsh, Richardson, & Faulkner, 1993). These links play a key role in many intelligent processes that semantic organization supports. For example, associations such as *animal-zoo* can support inferring that *dax* is an animal upon hearing *dax* with *zoo* (Sloutsky, Yim, Yao, & Dennis, 2017).

Semantic organization also comes to be organized according to *taxonomic* links between concepts that belong to the same stable semantic category (e.g., fruits), whose labels are thus similar in meaning (e.g., *apple* and *pear*). Like associative links, taxonomic links are fundamental to semantic organization and the intelligent processes it supports, such as generalization. For example, upon learning that apples are a rich in vitamins, people can extend this knowledge to other fruits (Gelman, 2009; Gelman & Meyer, 2011; Heit, 2000; Sloutsky, 2010). However, numerous studies suggest that taxonomic links emerge more gradually than associative links over semantic development (Bjorklund & Jacobs, 1985; Blaye et al., 2006; Tversky, 1985; Unger et al., In Press).

Together, associative and taxonomic links provide rich, meaningful structure to semantic knowledge. How are these links formed in the course of development?

Co-occurrence Regularities as Drivers of Semantic Development

To date, numerous accounts of semantic organization development have been proposed that focus on the emergence of taxonomic links (Gelman & Markman, 1986; Quinn & Eimas, 2000; Sloutsky, 2010; Smith & Heise, 1992). Although these accounts might provide some valuable insights into semantic development, here we consider how *both* associative and taxonomic links may emerge from simple but powerful sensitivities to co-occurrence regularities in language (Figure 1). Specifically, we propose that associative links may be formed from the regularities with which words *directly* co-occur together (either adjacent or separated by intervening words, e.g., *juicy-apple; juicy-pear*), and taxonomic links from regularities with which words share patterns of direct co-occurrence with other words (e.g., *apple-pear*). Henceforth, we refer to this proposal as the Co-Occurrence Account.

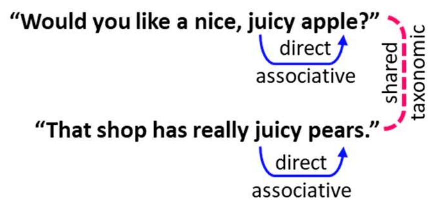

Figure 1: Direct and shared co-occurrence regularities that can form associative and taxonomic links.

The potentially powerful contributions of co-occurrence regularities are highlighted by extensive evidence that language is rich in co-occurrence regularities that can capture meaningful semantic links between words. First, much of the variability in the strength of semantic links between words can be predicted by the regularity with which words directly co-occur, or share co-occurrence (Hofmann, Biemann, Westbury et al., 2018; Spence & Owens, 1990). Moreover, extensive computational modeling research attests that simulated representations of words based on their patterns of co-occurrence in language predict complex semantic phenomena, from human semantic similarity judgments to the typical vocabulary growth rate of schoolchildren (Jones et al., 2015; Landauer & Dumais, 1997). Together, this research provides evidence that language is rich in regularities that can in principle foster meaningful semantic links between new and familiar words.

The plausibility of the proposed role for co-occurrence regularities is further underlined by evidence that sensitivities to these regularities in a variety of domains emerge in the course of development. For example, extensive statistical learning research attests that an ability to link inputs such as speech sounds (Saffran, Aslin, & Newport, 1996), images (Fiser & Aslin, 2002), and pairs of novel words (Wojcik & Saffran, 2015) emerges early in development. A handful of findings are also suggestive of sensitivities to shared co-occurrence in some domains that may emerge more gradually. For example, Schlichting, Guarino, Schapiro, Turk-Browne, and Preston (2017) observed a gradually-developing ability to link pairs of images that had never been seen together, but had both been paired with the same, third image. Similarly, studies conducted by Bauer and colleagues (e.g., Bauer & Larkina, 2017) have shown developmental improvements in abilities to integrate together two "stem facts" that both link new information to the same concept (e.g., *dolphins communicate by clicking and squeaking* and *dolphins live in pods*) to derive a new fact (e.g., *pods communicate by clicking and squeaking*).

Together, these lines of evidence provide strong support for the Co-Occurrence account of semantic organization development. In the next section, we outline how this account may explain developmental changes in semantic organization.

Co-occurrence Regularities as Drivers of Developmental Changes in Semantic Organization

As described above, numerous investigations into the development of semantic organization suggest that associative links emerge early, and are more gradually supplemented by taxonomic links. The Co-Occurrence account can explain this trajectory in one of three ways.

The first potential explanation for developmental changes in semantic organization emphasizes the role of the experience. Specifically, abilities to form semantic links from direct and shared co-occurrence regularities may both emerge early in development. However, developing learners may need to first observe direct co-occurrence regularities. Only once direct co-occurrence-based links become robust may learners be able to integrate across overlapping direct co-occurrence-based links to form shared co-occurrence-based links (Sloutsky et al., 2017).

A second possibility is that the ability to form semantic links from direct co-occurrence emerges early, and is only gradually supplemented by abilities to form shared co-occurrence-based links (Schlichting et al., 2017).

Finally, even abilities to form direct co-occurrence-based links may improve with development. Because shared co-occurrence-based links can only be derived from overlapping direct co-occurrence-based links, improvements in abilities to form direct co-occurrence-based links may collaterally improve the formation of shared co-occurrence-based links.

Present Experiments

The primary goal of the present study was to test the fundamental Co-Occurrence account assertion that direct and shared co-occurrence regularities in language act as simple but powerful drivers of semantic organization development. To accomplish this goal, we investigated the development of abilities to form semantic links from direct and shared co-occurrence regularities. Moreover, we designed this study to investigate how the emergence of these abilities may account for developmental changes in the organization of semantic knowledge according to associative and taxonomic links.

In our experiments, we exposed 4-year-old children and adults to sentences in which novel words either directly co-occurred or shared co-occurrence with familiar words (Figure 2). We then tested whether participants formed corresponding semantic links between novel and familiar words using two measures. Specifically, we tested whether participants: (1) Produced words that directly co-occurred or shared co-occurrence with prompt words in a child-friendly adaptation of a free association task (Sentence completion), and (2) Labeled images of the familiar words using the novel words with which they shared co-occurrence.

Experiment 1

To measure the development of sensitivity to Direct and Shared co-occurrence regularities in language, young learners (4-year-olds) and adults were read sentences containing regularities in which novel words both Directly co-occurred and Shared co-occurrence with familiar words (Figure 2).

We specifically designed the study to test for formation of semantic links between novel and familiar words for two reasons. First, we wanted to track formation of *novel* semantic links based only on co-occurrence regularities. Second, the inclusion of familiar words allows us to test both whether novel concepts become linked with the specific familiar concepts (those that they co-occur with, e.g. apple – mipp), and whether these links *generalize* to other members of the same category (e.g., mipp – fruits). The proof that links based on Shared co-occurrence can support generalization is critical here, as generalization is the key property of taxonomic relations.

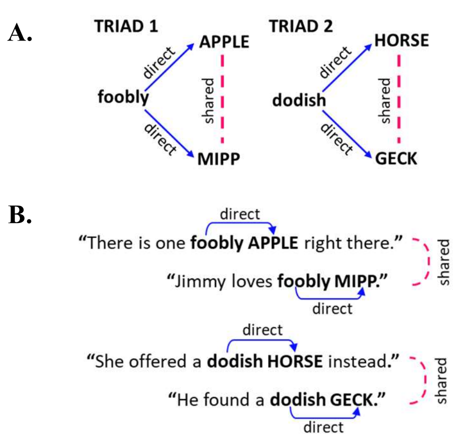

Figure 2: Panel A. Illustration of the two triads. Panel B. Examples of training sentences.

More specifically, during the training phase, participants heard sentences in which, a pseudoadjective (Triad 1: foobly; Triad 2: dodish) was paired with either the familiar noun (Triad 1: APPLE; Triad 2: HORSE), or the pseudonoun (Triad 1: MIPP; Triad 2: GECK) from the same Triad of words (see Figure 2). Thus, the familiar word in each Triad both Directly co-occurred with one novel word, and Shared co-occurrence with (but never appeared in the same sentence as) another novel word.

Critically, each Directly co-occurring pair (e.g., foobly - APPLE and foobly - MIPP) was embedded within a separate set of unique sentences that provided no additional information from which the meanings of the novel words could be derived (e.g., "Sally saw a foobly mipp").

Immediately following training, participants were tested in two tasks (see Figure 3). The production task, i.e. Sentence completion, was used to measure participants' sensitivity to Direct and Shared regularities. Generalization task, i.e. Label Extension, was designed to measure abilities to generalize based on Shared co-occurrence links.

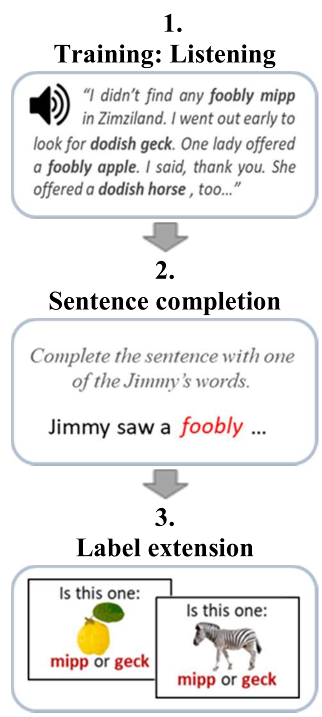

Figure 3: Illustration of three parts of the experiment: Training, Sentence completion and Label extension task.

Method

Participants Participants were 33 4-year-old children and 30 adults. Children were recruited from preschools and childcares on the basis of returned parental permission forms. Adults were The Ohio State University undergraduate students, and they received course credits for their participation.

Stimuli The training stimuli were two Triads of words (Triad 1: foobly-APPLE-MIPP; Triad 2: dodish-HORSE-GECK). Each Triad consisted of a pseudoadjective (foobly; dodish), familiar noun (APPLE; HORSE), and a pseudonoun (MIPP; GECK) (see Figure 2). Within each Triad, the pseudoadjective was paired with (a) the familiar noun and (b) the novel pseudonoun. These four pairs of words (foobly-

APPLE, foobly-MIPP, dodish-HORSE, and dodish-GECK) were presented to participants embedded in sentence frames.

Each word pair from the two Triads was embedded in 10 unique sentence frames, for a total of 40 training sentences. To ensure that semantic links formed between the words from the two Triads could be attributed only to exposure to co-occurrence regularities, sentences frames were neutral and did not convey any cues to pseudoword meaning. All the sentences were recorded by a female speaker in a child friendly voice, and thus were presented to the participants auditorily.

For the purpose of the Sentence Completion task, 30 novel sentence frames were constructed. Each of the six triad words was paired with 5 of these sentence frames. In addition, stimuli set included 48 pictures of mammals (24) and fruits (24), used in Label Extension task.

Procedure

The experiment had three parts: Training, Sentence completion task and Label extension task (see Figure 3). Participants completed all three parts within one half-an-hour session.

In Training, participants were told that they will hear "silly stories" told by a character, "Jimmy", who sometimes uses "silly words". They then heard two stories, each containing 40 training sentences, while watching child-friendly videos that did not contain narrative content.

Immediately following training, participants completed Sentence completion task. In Sentence completion task participants were asked to use "Jimmy's silly words" to complete stem sentences. The stem sentences always ended with one of the Triad words, which therefore served as cues for participants to produce a word from the same triad (e.g. "Jimmy saw a foobly ____"). Participants were presented with 30 sentences, 5 sentences per cue word.

After the Sentence completion task, participants took part in a Label Extension task (see Figure 3), where they were prompted to label pictures of mammals and fruits using one of the two pseudonouns from the triads (i.e. mipp or geck). There was a total of 48 trials.

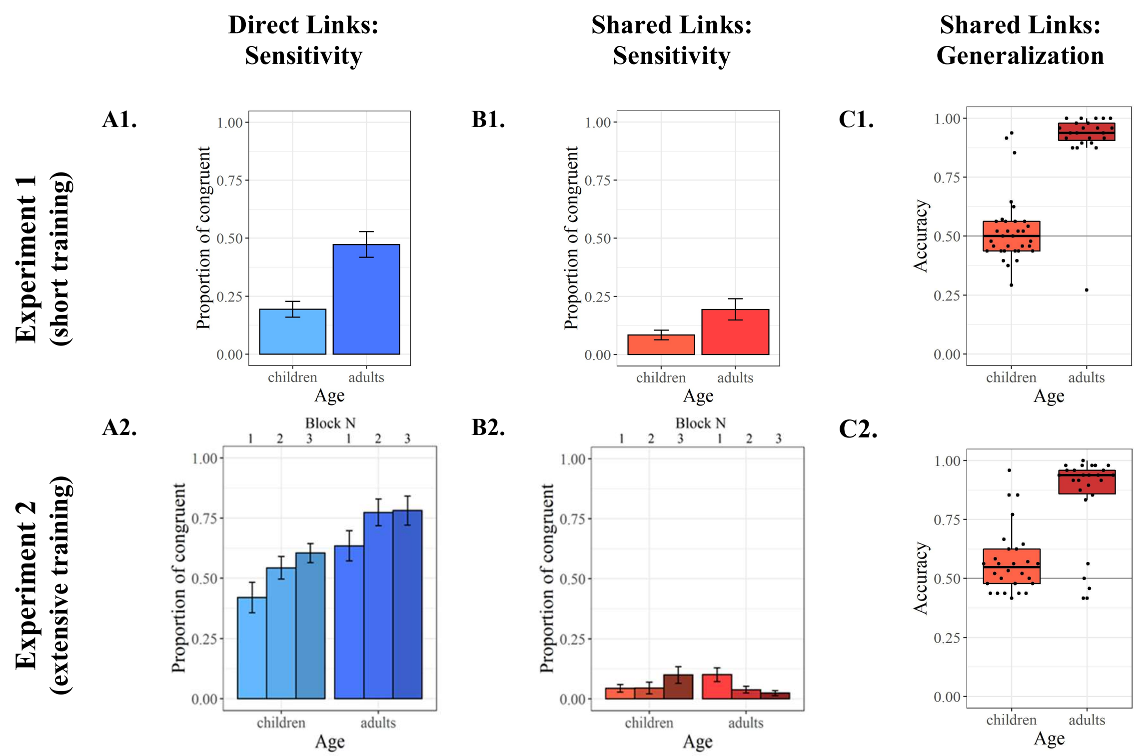

Figure 4: Proportion of responses based on Direct and Shared co-occurrence regularities in Sentence completion task and Accuracy in Label Extension task, in Experiment 1 and Experiment 2. Chance performance is 0 in the Sentence completion task and 0.5 in the Label Extension task.

Results

Preliminary analyses In Sentence completion task 4-year-olds responded with words from the triads (i.e. gave a valid response), on an average of 93% of all trials. Adult participants made more errors, and gave a valid response on 73% of all trials.

Further analyses included valid responses only. We additionally excluded word repetitions, multiple word responses and other response types that could not be coded.

This resulted in an additional removal of 2.2% of adult and 5.6 % of children responses.

Main analyses: Sensitivity to Direct and Shared Links Figure 4 shows average proportion of responses in Sentence completion task based on Direct (panel A1) and Shared (panel B1) co-occurrence regularities.

The proportion of the responses congruent with Direct and Shared co-occurrence regularities was corrected for guesses. Specifically, we subtracted proportion of incongruent (i.e., opposite Triad) responses from the raw proportion of congruent (i.e. same Triad) responses. The minimal value was set to 0 (random responding), and maximum to 1 (all responses congruent).

Both age groups made congruent responses based on Direct co-occurrence regularities at rates above chance level of 0, one sample t-tests against chance, $ts > 5.52$, $ps < .001$. However, there were significant developmental differences, with adults producing higher proportions of congruent Direct co-occurrence responses than children, $F(1,58) = 12.62$, $p < .001$, $\eta = .178$.

The proportion of responses based on Shared co-occurrences was low for both age groups (children: $M = .08$, $SD = .12$; adults: $M = .19$, $SD = .24$), but significantly greater than chance level of 0, both $ts > 4.01$, $ps < .001$. There were also significant developmental differences in the proportion of responses based on Shared co-occurrence, with adults outperforming children, $F(1,58) = 5.27$, $p = .025$, $\eta = .083$.

Main analyses: Generalization based on Shared Links

Patterns of results in Label extension task are shown in Figure 4, panel C1. In this task, we found striking developmental differences, $F(1,58) = 97.72$, $p < .001$, $\eta = .648$. In accordance with their performance in Sentence completion task, children were at chance level of .50, $t(31) = 0.90$, $p = .377$. On the other hand, adults were above chance, $t(22) = 13.56$, $p < .001$. While only 5 out of 32 children had above chance accuracy (i.e., above .62 based on binomial distribution), more than 90% of adults performed above the chance. This suggests that in contrast to children, adults could rely on Shared co-occurrence links to label familiar fruits and mammals using newly learned words.

Experiment 2

We have found significant developmental differences in Experiment 1. Although both age groups were given equal exposure to the regularities, adults performed better than children on both of the 3 measures: (a) Sensitivity to Direct co-occurrence regularities, (b) Sensitivity to Shared co-occurrence regularities, and (c) Ability to rely on Shared co-occurrence links to perform generalization.

The patterns of results found in Experiment 1 provided initial evidence that sensitivity to Direct co-occurrence regularities might start emerging early, but that abilities to form links based on Shared regularities may not be available until later in development.

Another potential explanation of the results of the Experiment 1 is that young children showed no sensitivity to Shared co-occurrence regularities simply because they formed weak Direct co-occurrence links. Since there is extensive evidence coming from statistical learning literature suggesting that sensitivity to Direct co-occurrence regularities develops early, it is possible that due to the other factors (e.g. lack of attention at training) and not their ability to form links per se, 4-year-olds in Experiment 1 simply underperformed.

To address this possibility, in Experiment 2, 4-year-olds and adults were given more training. Specifically, the training phase of Experiment 1 was repeated 3 times. At the end of each of the 3 blocks of training, participants completed Sentence completion task. At the very end, participants took part in Label extension task.

Participants in Experiment 2 were 28 4-year-old children and 32 adults, who did not take part in Experiment 1. They were trained using the same materials and following the procedures describes for Experiment 1.

Results

Preliminary analyses Following the same approach as described for Experiment 1, we first calculated the proportion of valid responses (i.e. responses that were words from the training Triads). Children gave on average 87.5%, and adults 91% of valid responses. In addition to exclusion of invalid responses, 1.3% of adults and 3.3% of children responses were excluded from the final analyses.

Main analyses: Sensitivity to Direct and Shared Links As it can be seen on panel A1 of Figure 4, both children and adults demonstrated above-chance formation of Direct co-occurrence links in the Sentence completion task, one sample $ts > 18.87$, $ps < .001$. To compare children and adults' formation of Direct co-occurrence links over the course of the three Training blocks, we conducted a two-way mixed ANOVA in which we predicted Direct co-occurrence link formation based on Age (between subjects; 4-year-olds vs. adults) and Training block (within subjects; one vs. two vs. three blocks). This analysis revealed that training improved the formation of Direct co-occurrence links in both age groups, $F(1.67,95.08) = 8.29$, $p < .001$, $\eta = .036$. In addition, adults again performed better than children, $F(1,57) = 13.39$, $p < .001$, $\eta = .148$. The two factors did not significantly interact ($p > .10$).

In the same task, evidence for the formation of Shared co-occurrence links was above chance (children: $M = .06$, $SD = .14$; adults: $M = .05$, $SD = .11$; one sample $ts > 4.11$, $p < .001$). A two-way mixed ANOVA with Age (between subjects; 4 versus adult) and Training Block (within subjects; one versus two versus three blocks) revealed only a significant effect of the interaction of the two factors, $F(1.65,93.80) = 5.28$, $p = .010$, $\eta = .050$, with no significant main effects. This interaction was driven by a slight reduction in Shared co-occurrence responses over blocks of training in adults, but not in children. Similar as in Experiment 1, we overall observed very low rates of Shared co-occurrence responses. Therefore, the reduction in adults, may be a side-effect of the fact that Sentence Completion assesses only participants' dominant responses. Thus, the dominance of Direct co-occurrence responses collaterally precludes Shared co-occurrence responses.

Main analyses: Generalization based on Shared Links

Replicating results of Experiment 1, we found significant developmental differences in the ability to use Shared co-occurrence links to support generalization, $F(1,57) = 35.02$, $p < .001$, $\eta = .407$. The majority of adults (80%) and only 20% of children performed above the chance ($ts > 2.64$, $ps < .014$).

Dependence of Shared Co-Occurrence Links on Direct Co-Occurrence Links

The preceding analyses provided evidence that abilities to form both Direct and Shared co-occurrence links undergo improvement with development. This pattern was particularly pronounced for Shared co-occurrence links.

Here, we analyzed whether these developmental patterns reflect (a) independent development trajectories for abilities to form Direct and Shared co-occurrence links, or (b) the dependence of abilities to form Shared co-occurrence links on abilities to form Direct co-occurrence links. Specifically, we tested whether to the strength of Direct co-occurrence links (i.e. proportion of responses based on Direct co-occurrence in the final block of the Sentence completion task of Experiment 2) can predict performance in the generalization task (i.e., accuracy in the Label extension) beyond the effect of Age.

Hierarchical regression analyses showed that Age explained a significant amount (40%) of variance in Label extension task, $F(1,51) = 35.03$, $p < .001$. Importantly, introducing the strength of the Direct co-occurrence links explained an additional 12% of variance. This change in R^2 was statistically significant, $F(2,51) = 4.13$, $p < .001$.

This pattern provides evidence that the development of abilities to form Direct co-occurrence links predicts the formation of Shared co-occurrence links above and beyond age.

General Discussion

Language is rich in co-occurrence regularities that can foster formation of both associative and taxonomic links (Jones et al., 2015; Landauer & Dumais, 1997. Thus, co-occurrence regularities represent a potentially powerful, but often overlooked, driver of semantic organization development. Across two experiments, we observed that exposure to co-occurrence regularities in language does indeed foster the formation of novel semantic links in both children and adults.

We further found significant developmental differences in abilities to form semantic links from both Direct and Shared co-occurrence regularities in language. Critically, although strength of Direct co-occurrence links in four-year-olds significantly improved with the extensive training, the great majority of them failed to rely on links based on Shared co-occurrence in generalization task. In contrast, adult participants performed well in both tasks.

The results of Experiment 2 further expanded on the results of Experiment 1 by providing evidence that the ability to form and use Shared co-occurrence links depends in part on the ability to form Direct co-occurrence links. Specifically, the formation of Direct co-occurrence links (measured from the Sentence Completion task) predicted generalization on the basis of Shared co-occurrence links (measured from the Label Extension task) above and beyond age.

Comparison of performance of children in Experiment 2 and adults in Experiment 1 offers additional evidence. Direct co-occurrence links in 4-year-olds by the end of Experiment 2 ($M = .61$, $SD = .41$) were comparable, and even stronger, $F(1,163) = 4.23$, $p < .05$, $\eta = .025$, than Direct co-occurrence links in adults in Experiment 1 ($M = .47$, $SD = .41$). However, despite the comparable strength of Direct links in these two groups, there were striking developmental differences in abilities to rely on Shared links (Label extension task). This suggests that formation of robust Direct links is not sufficient for formation of Shared links. Instead, learner also needs to have developed ability to integrate information across overlapping Direct co-occurrence patterns.

Reasons for Protracted Taxonomic Development

Taken together, the results of these experiments support the general assumption of Co-Occurrence Account of more gradual development of taxonomic versus associative links, and further illuminate the role of learning mechanisms that can explain this development.

First, these results suggest that associative links emerge early because they rely on early-emerging abilities to form Direct co-occurrence links. However, even abilities to form Direct co-occurrence links improve with development. Because forming Shared links relies on Direct links, the development of abilities to form Shared co-occurrence links is driven in part by the development of abilities to form Direct co-occurrence links.

Our findings support this hypothesis of *interdependence of* developmental trajectories for abilities to form Direct and Shared co-occurrence links and hence the account that highlights the role of *maturation of the ability to from Direct co-occurrence links.* Importantly, Shared links pose the added challenge of integrating together overlapping Direct co-occurrence links, and we find that this ability also undergoes development. Thus, taxonomic links may emerge gradually (a) because they are dependent on development of abilities to form Direct co-occurrence links and (b) because the ability to integrate Direct co-occurrence links matures slowly.

Acknowledgments

This work was supported by National Institutes of Health Grants R01HD078545 and P01HD080679 to Vladimir Sloutsky.

References

Bauer, P. J., & Larkina, M. (2017). Realizing relevance: The influence of domain-specific information on generation of new knowledge through integration in 4-to 8-year-old children. *Child Development, 88*, 247-262.

Bjorklund, D. F., & Jacobs, J. W. (1985). Associative and categorical processes in children's memory: The role of automaticity in the development of organization in free recall. *Journal of Experimental Child Psychology, 39*, 599-617.

Blaye, A., Bernard-Peyron, V., Paour, J.-L., & Bonthoux, F. (2006). Categorical flexibility in children: Distinguishing response flexibility from conceptual flexibility. *European Journal of Developmental Psychology, 3*, 163-188.

Coley, J. D. (2012). Where the wild things are: Informal experience and ecological reasoning. *Child Development, 83*, 992-1006.

Cree, G. S., & Armstrong, B. C. (2012). Computational models of semantic memory *The cambridge handbook of psycholinguistics* (pp. 259-282). Cambridge: Cambridge University Press.

Fenson, L., Vella, D., & Kennedy, M. (1989). Children's knowledge of thematic and taxonomic relations at two years of age. *Child Development, 60*, 911-919.

Fiser, J., & Aslin, R. N. (2002). Statistical learning of new visual feature combinations by infants. *Proceedings of the National Academy of Sciences, 99*, 15822-15826.

Gelman, S. A. (2009). Learning from others: Children's construction of concepts. *Annual Review of Psychology, 60*, 115-140.

Gelman, S. A., & Markman, E. M. (1986). Categories and induction in young children. *Cognition, 23*, 183-209.

Gelman, S. A., & Meyer, M. (2011). Child categorization. *Wiley Interdisciplinary Reviews: Cognitive Science, 2*, 95-105.

Heit, E. (2000). Properties of inductive reasoning. *Psychonomic Bulletin & Review, 7*, 569-592.

Hofmann, M. J., Biemann, C., Westbury, C., Murusidze, M., Conrad, M., & Jacobs, A. M. (2018). Simple co-occurrence statistics reproducibly predict association ratings. *Cognitive Science, 42*, 2287-2312.

Jones, M. N., Willits, J., & Dennis, S. (2015). Models of semantic memory. In J. Busemeyer & J. Townsend (Eds.), *Oxford handbook of mathematical and computational psychology* (pp. 232-254). New York, NY: Oxford University Press.

Landauer, T. K., & Dumais, S. T. (1997). A solution to plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review, 104*, 211.

Lin, E. L., & Murphy, G. L. (2001). Thematic relations in adults' concepts. *Journal of Experimental Psychology: General, 130*, 3-28.

McClelland, J. L., & Rogers, T. T. (2003). The parallel distributed processing approach to semantic cognition. *Nature Reviews Neuroscience, 4*, 310-322.

Quinn, P. C., & Eimas, P. D. (2000). The emergence of category representations during infancy: Are separate perceptual and conceptual processes required? *Journal of Cognition and Development, 1*, 55-61.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science, 274*, 1926-1928.

Schlichting, M. L., Guarino, K. F., Schapiro, A. C., Turk-Browne, N. B., & Preston, A. R. (2017). Hippocampal structure predicts statistical learning and associative inference abilities during development. *Journal of Cognitive Neuroscience, 29*, 37-51.

Sloutsky, V. M. (2010). From perceptual categories to concepts: What develops? *Cognitive Science, 34*, 1244-1286.

Sloutsky, V. M., Yim, H., Yao, X., & Dennis, S. (2017). An associative account of the development of word learning. *Cognitive Psychology*, 97, 1-30.

Smith, L. B., & Heise, D. (1992). Perceptual similarity and conceptual structure. In B. Burns (Ed.), *Advances in psychology: Percepts, concepts, and categories* (Vol. 93, pp. 233-272). North-Holland: Elsevier.

Spence, D. P., & Owens, K. C. (1990). Lexical co-occurrence and association strength. *Journal of Psycholinguistic Research, 19*, 317-330.

Tversky, B. (1985). Development of taxonomic organization of named and pictured categories. *Developmental Psychology, 21*, 1111-1119.

Unger, L., & Fisher, A. V. (2019). Rapid, experience-related changes in the organization of children’s semantic knowledge. *Journal of Experimental Child Psychology, 179*, 1-22.

Unger, L., Savic, O., & Sloutsky, V. M. (In Press). Statistical regularities shape semantic organization throughout development. *Cognition,* 10.31234/osf.io/31232ruyn.

Walsh, M., Richardson, K., & Faulkner, D. (1993). Perceptual, thematic and taxonomic relations in children’s mental representations: Responses to triads. *European Journal of Psychology of Education, 8*, 85-102.

Wojcik, E. H., & Saffran, J. R. (2015). Toddlers encode similarities among novel words from meaningful sentences. *Cognition, 138*, 10-20.