CHILD DEVELOPMENT PERSPECTIVES

The Development of Lexical–Semantic Networks in Infants and Toddlers

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ABSTRACT—***Researchers have focused for decades on how young children learn individual words. However, they have paid less attention to how children organize their word knowledge into the network of representations that underlies our ability to retrieve the right words efficiently and flexibly when we need them. Although methodological limits have made it difficult to study the development of lexical–semantic networks, in recent work with new paradigms, infants and toddlers have shown that they organize their vocabulary systematically via both categorical and associative relations from around age 2. Combined with work demonstrating that lexical–semantic relations affect early comprehension, production, and learning, this emerging area of research suggests that scientists and practitioners would benefit from more comprehensive theories of language learning that include not only vocabulary development, but also the development of lexical–semantic networks.***

KEYWORDS—*language acquisition; semantic development; word learning*

Psychologists have long studied how young children learn individual words. However, words are not learned in isolation. For example, the word *banana* is learned in the context of eating; it is heard near words like *eat* and around related objects like apples (1). Consequently, adults' lexical–semantic systems are organized into rich networks of representations. Specifically, our *lexical–semantic network* is made of a lexical network (the connections between words; 2), a semantic system (our representations of concepts and categories; 3), and the intertwining of the two.

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As a result of this lexical–semantic structure, when a word is heard or retrieved, related words are activated (4, 5). This activation helps us retrieve the right words efficiently and flexibly when we need them. For example, when children hear the word *dinner*, the activation of related words like *cook* and *plate* facilitates the processing of upcoming words (6). Given the transient nature of the linguistic stream, predicting upcoming words can be crucial for comprehension (7). Additionally, this lexical–semantic network influences how adults learn new words. If related words or concepts are activated when learning a novel word, the novel word is consolidated more readily (8, 9). Understanding the structure of our lexical–semantic network has helped us understand language learning, production, and comprehension, as well as how knowledge is represented.

While decades of research have led to insight into the mature lexical–semantic network, methodological limits have made it difficult to study its development in young children. In this review, I highlight recent advances in our understanding of how the early lexical–semantic system is structured, showing that during word learning, toddlers encode connections between words, which are then leveraged for further learning and more efficient processing. I argue that the structure of the developing lexicon must be addressed by theories of language development.

INVESTIGATING LEXICAL–SEMANTIC NETWORKS VIA SEMANTIC PRIMING

Much of our understanding of adults' lexical–semantic networks stems from semantic priming experiments. In one variation of this experimental paradigm, participants decide whether each word in a series is a real word or a nonsense word; the series is organized so each real word is preceded by either a related or an unrelated word. The *semantic priming effect* occurs when adults respond more rapidly to a target word (e.g., *dog*) when the prime is related (e.g., *cat*) than when it is unrelated (e.g., *table*; 10). The semantic priming task is unparalleled in its contribution to understanding lexical–semantic networks. Unlike other methods, such as free association (11) and semantic

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fluency tasks (12), semantic priming is implicit and has allowed researchers to test nuanced hypotheses about the cognitive mechanisms underlying lexical–semantic processing (e.g., whether words are retrieved automatically or via explicit strategies; 13). In the past several decades, semantic priming experiments have revealed that mature word processing leads to activation of related words and (under some circumstances) inhibition of unrelated words, and that words are linked by similarities in meaning, use, and how they sound (see 5 for a review).

THE DEVELOPMENT OF LEXICAL–SEMANTIC NETWORKS IN INFANCY AND EARLY CHILDHOOD

Until recently, researchers have lacked the methods to explore lexical–semantic networks in infants and toddlers. New experimental paradigms based on semantic priming tasks for adults have emerged in the past decade to shed light on the development of lexical–semantic networks.

Developmental Trajectory

Across several experimental paradigms, evidence suggests that semantic priming effects emerge between 18 and 24 months. Using electrophysiological (14, 15) and behavioral methods (16–18), researchers have consistently found evidence for semantic priming in 24-month-olds, but the results are mixed for younger infants. One study using event-related potentials (ERPs) found neural evidence of semantic priming in 18-month-olds (19), while another found evidence of priming only in 18-month-olds with large productive vocabularies (15). In an experiment using the Intermodal Preferential Looking Priming (IPLP) task, a behavioral method, 21- and 24-month-olds, but not 18-month-olds, looked more to a target word's referent (e.g., to a picture of a cow after hearing the word *cow*) when the word was preceded by a sentence ending with a related word (e.g., *I saw a sheep*; 16, 17).

The fragility of priming effects before 24 months suggests that lexical–semantic links emerge in the second year and become more robust around toddlers' second birthday. Support for this developmental trajectory comes from auditory-only priming tasks (based on the Headturn Preference Procedure; 20), which mimic semantic priming tasks for adults. In one version of this task, on each trial, infants hear eight words presented repeatedly in a random order, played from speakers to their left or right (side is randomized across trials). Half the trials consist of words from the same category (e.g., *dog–pig–cat–sheep*) and half of words from different categories (e.g., *hat–ear–sock–tummy*). As in semantic priming experiments with adults, researchers compare infants' implicit reactions to related and unrelated trials. In this case, the dependent variable is how long infants look to the side from which the word list is played before they disengage. Eighteen-month-olds looked longer on trials that featured words from the same category than on trials featuring words from different categories (21), suggesting connections between related words at this young age.

A similar auditory paradigm (the Auditory Semantic Task, or AST) tested semantic priming in 24-month-olds. In the AST, each of 16 trials consists of two words (instead of eight) that are either related (e.g., *dog–kitty*; *shoe–sock*) or unrelated (e.g., *dog–shoe*). As in the study described earlier (21), the word pairs are presented repeatedly until the infant looks away from the side from which the words play, and the number of related and unrelated trials is equal. Each word is heard an equal number of times in unrelated and related pairs, so any differences between looking time in related and unrelated trials are due to the relationship between the words, not characteristics of individual words. When tested with this paradigm, 24-month-olds looked longer in *unrelated* trials (18), preferring a direction opposite to that of the 18-month-olds.

One prominent theory of attention suggests that infants look longer to familiar trials when the auditory stimuli are more difficult to process and longer to unfamiliar trials when the stimuli are easier to process (22). In auditory semantic priming tasks, related trials are analogous to familiar trials and unrelated trials to unfamiliar trials. If this theoretical extension is accurate, the flip in direction of preference would suggest that lexical–semantic relations are weaker at 18 months than at 24 months, which is congruent with other research on infant priming (15, 16). The contribution of neurological changes and experience to the development of lexical–semantic networks in the second year of life must be explored further, particularly in light of the effect of vocabulary size on the emergence of lexical–semantic relations (15).

Associative Versus Taxonomic Relations

In addition to the developmental trajectory, researchers have also investigated whether infants' lexical–semantic relations are based on taxonomic relatedness or association strength, a prominent debate in research on adults (23). Taxonomically related words are those whose referents share features and, typically, also belong to the same category (e.g., *dog–horse*). Associated words are those that are frequently generated by adults in a free association task, and thus are thought to represent direct links between word labels that are not necessarily mediated by overlaps in meaning (e.g., *dog–bone*; 11). If lexical–semantic networks are organized primarily by taxonomic category, then priming effects should be driven by taxonomic relatedness. However, if lexical–semantic networks are organized primarily by links between words themselves, then priming effects should be driven by association strength. Because words that are taxonomically related are often associated at least somewhat (*dog–cat, cookie–milk*), few agree on how, when, or even if each type of relation contributes to the semantic priming effect in adults (24).

The IPLP has been used to test associative and taxonomic priming in 21- and 24-month-olds, with evidence of priming for both at each age (25; although these results, like those with adults, are difficult to interpret because words that are

taxonomically related are often associated at least weakly). Additionally, ERP studies have found evidence of priming for unassociated but taxonomically related word pairs at 24 months (e.g., *dog–bear*; 14, 15). Although these results suggest that early lexical–semantic organization is both taxonomic and associative, this balance may change throughout development. In the first year, infants' conceptual system is fragile; they are just beginning to associate words with referents (26). However, at this age, they readily track statistical patterns in speech (27). Perhaps, then, early lexical–semantic networks are driven by this statistical learning. Words that co-occur, such as *eat–carrots*, may become associated and provide an early foundation for other types of relations, such as those based on conceptual similarity. Indeed, the co-occurrence of words in speech bootstraps infants' learning of the semantics of individual words (28). Researchers should probe different types of word relations in the first year.

ENCODING LEXICAL–SEMANTIC LINKS BETWEEN NOVEL WORDS

Do infants encode lexical–semantic relations from their first exposure to new words? The stimuli in most studies on infant priming are chosen because they are familiar, so it is unclear if newly learned words are connected into lexical–semantic networks immediately, or if word representations must be more robust and well known before relations are formed. Researchers have used the AST to investigate semantic priming between newly learned words (29, 30). In these experiments, 2-year-olds are exposed to four novel words organized into pairs of words related along only one dimension. For example, one study exposed toddlers to two pairs of novel words that had visually similar referents (two words were round and bluish, while the other two were red and pointy; 29). Typically, most words with visually similar referents also co-occur in speech and are seen in similar contexts, thus making it difficult to determine which dimension of relatedness drives priming effects. Is priming driven by the high frequency of *spoon* and *fork* occurring in the same sentence, by their referents' visual similarity, by their referents' functional similarity, or by their co-occurrence in events related to eating? Indeed, some argue that dissociating these types of relatedness is nearly impossible (23). By exposing infants and toddlers to a novel minilexicon, researchers can investigate the ontogeny of lexical–semantic relations and test hypotheses about the types of relationships encoded by infants and toddlers.

After exposure to the novel words, the same method is used to test semantic priming as in the familiar word AST paradigm (18). On each trial, infants hear a pair of the newly learned words, presented repeatedly from either their left or right, and researchers measure looking time to that side. Half of the 16 test trials are pairs of novel words that were related during training, and half are unrelated pairs. During testing, the infants hear only the labels of novel words; they do not see their referents or hear the words in sentences. Thus, any difference between looking time in related and unrelated trials is due to the relation that was encoded during the exposure phase.

When 2-year-olds learned new words in this paradigm, they readily encoded relations based on the visual similarity of the referents (29). Specifically, when two newly encoded words were related only by color of referent and similarity of shape, infants showed a priming effect between those word labels, in the absence of their referents, immediately after learning. Additionally, when exposed to sentences using novel words in systematic sentence positions, they encoded relations between words used in the same sentence (*The tursey broke the coro*; 30), demonstrating early encoding of lexical–semantic relationships based on co-occurrence in speech.

Not all word relations are readily encoded by young toddlers. Two-year-olds only encoded relations between words used in the same position across sentences (*The tursey broke the coro*; *The blicket broke the pif*) if they produced multiword utterances frequently (30). This type of cross-sentence relation is correlated with taxonomic similarity in most languages (e.g., *The dog shed its fur*; *The cat shed its fur*), so one hypothesis is that as toddlers learn about the syntax of their language, they begin to encode relations that reflect helpful links between syntax and meaning. Together, these studies on priming effects between novel words suggest that infants encode referential similarity and lexical co-occurrence when learning new words (supporting evidence from studies of familiar words that early relations are based on both taxonomic and associative relations; 25), but that other relations, such as similarity in syntactic position, only drive development of the lexical–semantic network later.

THE EFFECTS OF LEXICAL–SEMANTIC ORGANIZATION ON EARLY LANGUAGE COMPREHENSION AND WORD LEARNING

By the end of their second year, toddlers' knowledge of familiar and novel words is organized into a network of representations. This lexical–semantic structure affects how toddlers comprehend and learn language. First, 2-year-olds process familiar words faster if they also know many other words from the same category (31). In addition, eye-tracking evidence suggests that when 2-year-olds hear a noun but do not see a picture of the word's referent (e.g., they hear the word *banana* but do not see a picture of a banana), they look to pictures of the word's taxonomic and associated neighbors (in this example, *tomato* or *monkey*; 32). Combined with the semantic priming studies cited earlier, this work suggests that lexical–semantic relations meaningfully influence the speed and pragmatics of early word comprehension, yet most researchers do not consider lexical–semantic structure when designing experiments or developing theories.

Second, in recent simulations, the age of acquisition is earlier for words that are connected to many other words in children's

lexicons (e.g., the word *dog* is learned earlier if the child already knows many animal words), as well as for words that are heard near a variety of other words in speech to children (e.g., the word *dog* is learned earlier if it is heard in many different contexts; 33).

Further modeling is needed to tease out the complex relationship between lexical–semantic relations and word learning (see 33 for a discussion), but the work done so far suggests that word learning is affected not only by individual features of words (e.g., frequency or concreteness), but also by features of the lexical–semantic network. Indeed, infants process newly learned words faster if they already know many words from the same category (34).

REMAINING QUESTIONS

The field is now poised to tackle many unresolved questions that have implications for language learning and use. First, while evidence suggests that lexical–semantic relations are fragile before 21 months, we do not know why priming effects are unreliable at younger ages. Are words truly isolated before this age, or are the links too weak to be measured? If the latter, then manipulating task parameters or word relationships may draw out semantic priming in younger groups and reveal the characteristics of the earliest semantic networks. For example, younger infants may show stronger priming effects at different intervals between primes and words (as seen in adults; 10) or for words that co-occur in speech directed at children (as suggested by the theory of the early importance of co-occurrence over semantic overlap proposed earlier).

Second, researchers must explore types of conceptually based relations beyond taxonomic relations. A review of studies on semantic priming in adults found that priming effects are largest for words that are related functionally (e.g., *sweep–broom*; 24). If infants' early word relations are indeed based on associations in the input, as suggested earlier, toddlers may connect words that are related functionally first, as such words typically represent verb–noun chunks that co-occur in speech. Indeed, these functional semantic relationships may provide the foundation for or work in tandem with the development of function as an early organizer of word meaning.

Third, studies thus far have focused primarily on monolingual toddlers. One study with bilingual 30-month-olds found cross-language semantic priming effects in the IPLP only when the prime was in the dominant language (35). In studies using the AST, bilingual 24-month-olds show within-language semantic priming effects only in their dominant language, suggesting that language input affects the developmental trajectory of semantic networks (36). Additionally, in simulations, bilingual infants learn words faster when the words are connected to more words within and across languages (37). Further work with bilingual infants will not only shed light on their lexical–semantic networks, but also reveal how the language environment (e.g., number of languages, and quality and quantity of language input) affects the development of networks.

Finally, researchers must continue to explore how lexical–semantic networks affect word learning and vice versa. Novel words are integrated immediately into adults' lexical–semantic network only if introduced in a fast mapping task, in which participants are presented with a familiar and novel referent and must infer the correct label-referent mapping (9). Furthermore, cross-situational word learning, in which learners encode the meanings of words over time by tracking the probability that a specific referent occurs when a specific word is heard, is influenced by lexical–semantic relationships. In cross-situational experiments of word learning, adults learn novel words faster when they are presented in the context of members of a semantic category (38). Are novel words more rapidly integrated into toddlers' networks when surrounded by rich and related context, as suggested by studies of adults? If so, we need to adjust theories of early word learning to consider lexical–semantic networks.

Lexical–semantic relations emerge within the first 2 years of life, and this structure affects word learning and comprehension. Therefore, we must move beyond studying vocabulary development and individual word representations to examine semantic development more fully. Research on language learning would benefit from more comprehensive theories of word learning that include the development of lexical–semantic networks.

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