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Mapping sound to meaning:

Connections between learning about sounds and learning about words

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Outline

IV. I. Introduction

Human language is notorious for its multilayered structure. To acquire linguistic information at one level, such as how words pattern together to form grammatical structure, learners must already know something about the words themselves, such as their membership in grammatical categories (e.g., nouns versus verbs), or other characteristics of their meanings and/or syntactic features. Conversely, knowing something about syntactic structure can help learners make informed guesses about what novel words might mean (e.g., Gilette, Gleitman, Gleitman, & Lederer, 1999). Knowledge about one level of language (e.g., syntax) helps to constrain the hypotheses put forth at other levels of language (e.g., word meanings), and vice versa.

Mutually-constraining multiple levels of information act in the attempt to link sound to meaning in word learning as well. To figure out what words mean, learners must already have some idea of which sound sequences in their language correspond to words. However, relatively little research has focused on the process by which sound and meaning come together in word learning. A massive literature on how young children learn the meanings of words has focused primarily on the nature of the child's hypotheses about possible meanings, and on the objects, actions, or concepts to be mapped to sounds (e.g., Bloom, 2000; Markman, 1990; Woodward & Markman, 1998); far less is known about how knowledge of sound structure contributes to word learning. There is also a burgeoning literature on how infants acquire the sound structure of their language, including the acquisition of individual native language sounds (phonemes), how those sounds regularly combine (phonology, phonotactics), and which sound sequences are segmented from the speech stream as words (e.g., Jusczyk, 1997). Infants' prior learning about phonetic categories, sound sequence regularities, and word segmentation cues all likely contribute to the process of linking word forms with their meanings. Interestingly, however, the links between the early learning processes underlying the acquisition of native language sound patterns (which unfolds during the first year of life) and the mapping of those sounds to meaning (which primarily emerges during the second year of life), has only gained attention in the field since the beginning of the 21st century.

Our goal in this paper is to explore the potential links between the sounds of words and the word learning process. Initial learning about the sounds of a language may provide infants with a foundation for the subsequent association of sound sequences with meanings. To set the stage, we first briefly overview some relevant results in the field of infant speech processing (for thorough recent reviews, see Kuhl, 2004; Werker & Curtin, 2005; Saffran, Werker, & Werner, in press), and preview how representations of speech might relate to lexical development. We then highlight empirical and theoretical developments in two areas where learning about the sounds of language may be especially relevant for word learning: the phonetic specificity of early lexical representations, and how familiarity with the sounds of words affects word learning, specifically through the influence of phonotactic probability and neighborhood density, and the process of word segmentation. By doing so, we hope to provide suggestions for future research that will explicitly link together two very fruitful, but all too often separate, domains of research: infant speech perception and early word learning.

II. Overview

Since the 1980's, a large body of work has traced the development of infants' capacity to perceive phonetic contrasts (e.g., /p/ versus /b/). Infants rapidly become tuned to those phonetic contrasts that are used in their native language. Language-specific tuning in vowel perception is already evident by 6 months (e.g., Kuhl, Williams, Lacerda, Stevens, & Lindbloom, 1992). Consonant categories develop somewhat later, likely due to the relative prominence and clarity of vowels in infant-directed speech (e.g., Kuhl et al., 1997). At 6 to 8 months, infants can perceive both native language and non-native consonant contrasts that adults cannot discriminate. By 10 to 12 months, infants' attention becomes focused on the acoustic dimensions that are important for their native language (e.g., Werker & Tees, 1984).

Do infants use the fine phonetic distinctions acquired during the first year as the basis for subsequent word learning and word recognition? It seems likely that infants notice phonetic distinctions in new words, and then associate different meanings with different word forms. Data from a number of word learning experiments suggest that infants in fact do not have access to full phonetic detail in their lexical representations (e.g., Stager & Werker, 1997). However, the results of word *recognition* experiments (as opposed to word learning experiments) appear to contradict this conclusion (Swingley & Aslin, 2002). Although attempts to clarify the phonetic specificity of early words have received substantial research attention, this debate has not been resolved (Ballem & Plunkett, 2005; Fennell & Werker, 2003a; Swingley, 2003; Swingley & Aslin, 2005; Werker & Curtin, 2005).

In addition to advances in language-appropriate phoneme discrimination, infants also learn about how sounds are combined in their native language during their first year. By 9 months, but not at 6 months, infants can discriminate phoneme combinations in words that are legal in the native language from illegal combinations (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993), as well as common legal combinations versus rare but legal combinations (Jusczyk, Luce, & Charles-Luce, 1994). Knowledge of probable versus improbable phoneme combinations provides infants with a cue for segmenting words from fluent speech (Mattys &

Jusczyk, 2001; Mattys, Jusczyk, Luce, & Morgan, 1999). Learning about regularities in phoneme combinations may also contribute to word learning by influencing how readily new words are added to the lexicon. Words consisting of frequent sound sequences may be easier to associate with meanings because they contain phoneme combinations with which the infant is already familiar, allowing the infant to focus more attention on identifying the referent of the new word (its meaning). Alternatively, new words that are highly similar to familiar words may make associating meaning difficult because of the confusability of the word forms. This area of inquiry has only recently become the object of study in infant word learning experiments (Hollich, Jusczyk, & Luce, 2002; Swingley & Aslin, 2005).

To associate a meaning with a word, infants must be able to isolate the word form from fluent speech. Because fluent speech does not contain reliable acoustic markers of word boundaries, infants must learn about the regular sound patterns of their language and use this knowledge to find words in the speech stream. Between 7 and 11 months, infants develop the ability to take advantage of patterns of syllable-pair probabilities (e.g., Aslin, Saffran, & Newport, 1998; Saffran, Aslin, & Newport, 1996), as well as lexical stress (e.g., Johnson & Jusczyk, 2001; Jusczyk, Houston, & Newsome, 1999; Thiessen & Saffran, 2003), phonotactics (Mattys & Jusczyk, 2001), and allophonic cues (Jusczyk, Hohne, & Bauman, 1999) to isolate individual words.

Given that infants have access to a variety of segmentation cues to find words in fluent speech during the second half of the first year, they likely segment many word forms before they begin to map meanings to those forms. However, the nature of the relation between these processes has received little attention. One possibility is that infants parse continuous speech into isolated sound sequences, which then serve as candidate words, ready to be associated with meanings. That is, perhaps the segmentation process feeds directly into the process of mapping sound to meaning. Alternatively, infants may require additional experience with isolated sequences or need to hear them in new contexts before they can be associated with meanings. Although only a few studies have investigated how infants map meaning to recently segmented words (Hollich, in press; Swingley, 2002), this area hold promise for understanding the mechanisms underlying the early stages of vocabulary acquisition.

In the remainder of this chapter, we explore possible connections between infants' knowledge about the sound structure of their language and how infants map these sounds to meaning. In the first section we describe the debate about the phonetic specificity of early lexical representations, focusing on whether infants apply their fine-grained perceptual discrimination skills to word learning. In the second section, we address ways that familiarity with the sounds of words may affect infants' ability to link word forms to meaning, focusing on the acquisition of phoneme pattern regularities, and how this knowledge might affect the addition of new words to the infant's lexicon. Finally, within the second section we also ask how the process of word segmentation contributes to infants' association of word forms with meanings.

III. Phonetic specificity in early lexical representations

Studies of infant speech perception have amply demonstrated that even young infants possess prodigious speech discrimination skills. However, there has been considerable debate concerning the degree to which these sophisticated abilities are used in early word learning and word recognition. In a seminal study, Jusczyk and Aslin (1995) investigated the nature of infants' emerging lexical representations by testing whether 7.5-month-old infants would notice when pronunciations of familiarized words were altered slightly in the context of a word segmentation task. They proposed that if infants' memory for the familiarized items was vague and lacking in detail, the infants should fail to notice a slight change in pronunciation. However, Jusczyk and Aslin found that infants listened longer to the altered pronunciations than to the familiarized words, indicating that they recalled sufficient detail in the original items to avoid confusing the similar sounding pronunciations.

In contrast, Hallé and de Boysson-Bardies (1996) found that 11.5-month-olds listened longer to lists of frequent words (in French, e.g. "*bonjour*") than to infrequent words, and that this preference carried over to phonetically similar mispronunciations of the familiar words (e.g. "*ponjour*"). Hallé and de Boysson-Bardies suggested that the difference between their finding and Jusczyk and Aslin's (1995) results was that although both tasks could be performed successfully without knowledge of word meaning, 11-month-olds have started to associate meanings with words (unlike the 7-month olds tested by Jusczyk and Aslin), and this changes how they process language. Hallé and de Boysson-Bardies proposed that when listening for meaning, words are represented holistically rather than with fine-grained phonetic detail. On this view, the younger infants in Jusczyk and Aslin's (1995) study maintained more phonetic detail in their emerging word forms because they are not yet mapping those forms to meanings (but see Swingley, 2005a, and Vihman, Nakai, DePaolis, & Hallé, 2004, for alternative findings and interpretations).

Hallé and de Boysson-Bardies's findings support a long-standing claim from developmental phonology: the lexical representations of infants and young children are holistic, lacking in the detailed representations of phonetic segments that differentiates and organizes words in the fully developed phonological system. Many authors have argued that young children's lexical representations center on whole words (Ferguson 1986; Menyuk, Menn &

Silber, 1986; Pisoni, Lively, & Logan, 1993; Walley, 1993; Waterson, 1971), or other broad units such as syllables (Jusczyk, 1993). This differs from mature lexical representations, which contain fine-grained segmental structure that enables word recognition to occur given only partial acoustic-phonetic information; lexical access can proceed prior to the end of the word (Allopenna, Magnuson, & Tanenhaus, 1998; Marslen-Wilson, 1987). The organization of the adult lexicon is affected by representations of phonetic segments, such that similar sounding words activate one another, and as a word unfolds, alternative lexical candidates are excluded (e.g., Marlsen-Wilson, 1987). Adults may even represent subphonemic information about the sounds of words (e.g., McMurray, Tanenhaus, Aslin, & Spivey, 2003; Norris, McQueen, & Cutler, 2003).

In contrast, children's words are said to be represented as "unanalyzed wholes" (Walley, 1993, p. 293); little phonetic detail is required to differentiate them, and children need to hear the entire (or nearly the entire) word before identification. In her review of the role of vocabulary changes in phonological development, Walley (1993) proposed that limitations on attentional and memory capacity are at the root of the underspecified lexical representations of infants and young children. Storing words as holistic units is proposed to be adaptive: holistic representations would lend efficiency to word learning, and would be sufficient for lexical processing given a small vocabulary because there are few confusable entries.

Evidence for holistic lexical representations comes from a variety of experimental and observational methods, and from children at many different stages of vocabulary development. In particular, studies of children's attempts to learn similar sounding words rendered evidence for holistic representations at quite young ages (one to three years of age). In an early demonstration, Schvachkin (1948/1973) presented 10- to 18-month-olds with phonetically similar labels for objects (e.g., "*dak*" and "*gak*") using a variety of phonetic contrasts. Schvachkin found that children could not consistently select the correct objects for similar sounding labels, although with age (the children were followed longitudinally for approximately six months), they seemed to gradually gain access to more of the consonant contrasts tested. Other researchers (Brown & Matthews, 1997; Edwards, 1974; Eilers & Oller, 1976; Garnica, 1973) have attempted similar minimal-pair learning experiments. These studies have indicated that 1 1/2- to 3-year-olds have difficulty discriminating many phonetic contrasts in lexical tasks. However, Barton (1976, reviewed in Barton, 1980) found that when children were already familiar with the words tested, they were often able to discriminate a wide range of contrasts. Thus, the findings from young children's word learning studies indicate that processing of phonetically similar words is vulnerable and highly variable depending on factors such as age, the familiarity of words tested, and the contrasts tested.

Results from studies with older children also provide evidence for holistic lexical representations. Although production errors have been interpreted as support for immature phonological representations (e.g., Ferguson, 1986), many studies have used methods that reduce production demands to focus on underlying lexical representations. Gating tasks, in which participants are asked to identify familiar words with limited acoustic information (e.g., 100 ms of the word, followed by 150 ms, then 200 ms), indicate that children require more information to recognize words than adults (Elliott, Hammer, Evan, 1987; Walley, 1988). In mispronunciation tasks, children age four and five are much less accurate than adults at identifying changes to familiar words presented within sentences (Cole, 1981, see also Walley & Metsala, 1990). Cole and Perfetti (1980) also argued that because children, unlike adults, are not better at identifying second syllable errors than first syllable errors, children must wait longer to identify a word than adults; younger listeners need to hear more of a word prior to identifying it. Word familiarity also affects how readily children recognize words. Walley and Metsala (1990) found that 5- and 8-year-old children were more likely to detect mispronunciations of words they had not learned recently (see also Garlock, Walley, and Metsala, 2001). Taken together, this evidence suggests that children's lexical representations lack the detail of adult representations and the representations improve with experience with words.

Charles-Luce and Luce (1990, 1995) took a different approach to investigate the notion of holistic representations. Using corpus analyses, they asked whether the words in the child's existing lexicon are phonetically dissimilar enough to support holistic processing, or whether instead processing that lacks phonetic detail would lead to a great deal of word confusions. To do so, they compared the similarity neighborhoods of words in 5- and 7-year-olds' and adult lexicons. Similarity neighborhood, or phonological neighborhood, refers to the number of words that differ from a given word by one phoneme deletion, substitution, or addition. Children's productive vocabularies contained fewer neighbors than the adult lexicon. Similar results emerged from an analysis of words in infant-directed speech, which they used as a surrogate measure of infants' receptive vocabulary. Charles-Luce and Luce concluded that children could maintain holistic representations without sacrificing word discrimination because the child lexicon contains sufficiently few confusable words (for opposing views, see Coady & Aslin, 2003; Dollaghan, 1994). They proposed that holistic representations may even be adaptive, as attention is not wasted on superfluous detail.

The claim that children do not use phonetic detail in word learning and recognition seems to conflict with myriad findings demonstrating that infants represent speech in exquisite detail (reviewed in Kuhl, 2004; Werker & Curtin, 2005; Saffran, Werker, & Werner, in press). A reasonable supposition from the research exploring infants' speech perception skills is that by the end of the first year of life, infants are well-equipped to apply their sophisticated discrimination abilities to word learning and recognition. Yet several researchers have argued that the phonetic representations and analytic processes used in infant speech perception tasks are not the same as the phonological representations used in word learning, recognition, and production (Pisoni et al., 1994; Jusczyk, 1992; Studdert-Kennedy, 1986; Walley, 1993) and that phonetic perception is not adult-like until middle childhood, around age 6 or 7 (e.g., Nittrouer & Studdert-Kennedy, 1987). One explanation offered for this potential discrepancy is that infants process speech stimuli as meaningless sounds. The phonetic tuning that occurs in the first year relates to later learning only in that it sets the boundaries for the sounds that may be relevant in the native language. Later developing, mature speech processing emerges as the child begins to interpret discriminable elements as members of different categories (Ingram, 1989; see also the review in Walley, 1993). The representations used for word learning and recognition must be built.

The hypothesized driving force behind the emerging specification of lexical representations is vocabulary development itself (Charles-Luce & Luce, 1990, 1995; Ingram, 1989; Jusczyk, 1992, 1993; Walley, 1993). For example, Walley (1993) links the start of the development of detailed representations to the vocabulary spurt at around 18 months, with continued development into middle childhood. According to a holistic representation account, as the lexicon expands, words become increasingly confusable. As more overlapping words are added to the lexicon, there is increased pressure to precisely differentiate words; holistic representations can no longer adequately represent every word as an entity distinct from the rest of the child's vocabulary (Brown & Matthews, 1997; Charles-Luce & Luce, 1990, 1995; Jusczyk, 1993; Metsala, 1997; Walley, 1993). The restructuring of lexical representations is proposed to proceed in a gradual matter, at a different pace for different sounds depending on the number of similar sounding words in the lexicon. Eventually, children begin to represent words as consisting of segmental units, allowing for incremental and unique identification of lexical items. Learning to read promotes further specification, enabling children to gain conscious access to phonemes (Walley, 1993).

A. A re-examination of phonetic detail in word learning

Janet Werker and her colleagues (Fennell & Werker, 2003a; Stager & Werker, 1997; Werker, Fennell, Corcoran, & Stager, 2002) approached the study of early lexical representations with a new method, one with minimal task demands designed to be more sensitive than the explicit judgment and object selection tasks used in previous research with young children. As has been shown in the area of infant cognition (e.g., Keen, 2003; Munakata, McClelland, Johnson, & Siegler, 1997), tasks differing in the demands they place on children (e.g., looking versus reaching) may access different levels of knowledge representations. Tasks that require less overt or less complex responses may tap perceptions or knowledge that are not apparent in more challenging tasks which require stronger representations and greater coordination of knowledge representations and the means for expressing that knowledge. Thus, a task that requires children to watch objects on a monitor should allow them to express underlying knowledge more readily than a task that requires physically selecting objects from an array (e.g., Schvachkin, 1948/1973) or making meta-linguistic judgments (e.g., Cole, 1981). As Werker and Fennell (2004) explained, Werker's research group originally expected that this simple habituation-based word learning task would tap infants' previously acquired knowledge about phonetic categories. However, this was not the case. Although the results of their experiments at first appear to support the notion that early representations are holistic, Werker and colleagues have come to different conclusions about the nature of early lexical representations.

In Werker, Cohen, Lloyd, Casasola and Stager's (1998) word-object association task, the infant is first habituated to two novel word-object combinations played over a video monitor and speakers, one at a time. Following habituation (i.e., a decrease in looking time), the infant is tested with two types of test trials: "same" trials, in which the original word-object pairs are presented, and "switch" trials, in which the words and objects are presented in novel pairings (i.e., Object 1 appears with repetitions of Word 2). If infants learn the original word-object associations, the pairings in the switch trials should violate this newly learned expectation, leading to longer looks on switch trials than same trials. In fact, Werker et al. (1998) found that 14-month-olds, but not younger infants (8- to 12-month-olds), could learn phonetically dissimilar word-object pairings ("*lif*" and "*neem*"). Fourteen months is similar to the age at which other researchers have been successful at teaching infants novel words with limited laboratory-based exposure (e.g., Ballem & Plunkett, 2005; Schafer & Plunkett, 1998; Woodward, Markman, & Fitzsimmons, 1994).

The word-object association task provides a useful method for measuring infants' ability to map words to their meanings while requiring minimal task demands. Clearly, the word-object association task does not incorporate the rich understanding of meaning commonly measured in older children and adults. Object identity serves as a highly simplified representation of meaning, yet this task does retain an essential quality of the process of word leaning—the formation of an arbitrary association between a meaning representation and a sound representation.

Stager and Werker (1997) used the word-object association task to investigate whether 14-month-olds could apply their sophisticated phonetic discrimination skills to associate sound and meaning. Infants attempted to form word-object associations for the novel words "*bih*" and "*dih*"; these two syllables are a minimal pair, differing only in a single phonetic feature (here, the place of articulation of /b/ versus /d/). The 14-month-olds looked equally long to same and switch trials, indicating that they failed to learn the labels. However, 14-month-olds could perform the perceptual discrimination of "*bih*" from "*dih*" in an object-free task; their failure in the word-object association task is not because they could not discriminate the sounds. Instead, the infants' difficulties appear to lie in mapping the labels onto the objects or the quality of the representations linked in the mapping. Infants' difficulty learning similar sounding word-object associations has been replicated with more phonotactically probable novel words ("*bin*" and "*din*"), as well as additional feature contrasts (i.e., "*bin*" versus "*pin*", "*din*" versus "*pin*") (Pater, Stager, & Werker, 2004).

Stager and Werker (1997) attempted to simplify the task by habituating infants to a single word-object pair ("*bih*" with Object 1) and testing whether infants would dishabituate when hearing the alternative word with the original object ("*dih*" with Object 1). Fourteen-month-olds again showed no difference in looking time to the original versus switched word-object pairs (see also Pater et al., 2004). However, 8-month-olds dishabituated to the switch. Stager and Werker suggested that for 8-month-olds, the task is one of simple sound discrimination that does not involve attempting to link the word with the object. In contrast, 14-months-old infants process words as potential sources of meaning whenever possible referents are available. The authors proposed that novice word learners, such as 14-month-olds, cannot attend to fine phonetic detail in new words because their computational resources are consumed by the attempt to map the sound sequence to a meaning.

Werker and colleagues (2002) tested the prediction that older infants, who are more proficient word learners, should be able to attend to phonetic detail when forming new sound-meaning associations. They compared word-object association performance of 14-, 17-, and 20-month-old infants. At around 17 to 18 months, infants typically begin to add new words to their receptive and productive lexicons at a rapid rate (Bates, Dale, & Thal, 1995). Therefore 17- and 20-month-olds should provide a good comparison for 14-month-olds, who know substantially fewer words. Although the 14-month-olds continued to show no difference in looking time on same and switch trials, the 17- and 20-month-olds showed significantly longer looking time during switch test trials, indicating that the older infants *were* able to learn the minimal pair labels.

This pattern of results was subsquently bolstered by an ERP study of the detail in children's lexical representations (Mills et al., 2004). Infants listened to lists of novel words (e.g., "*keed*", "*zav*"), known words (e.g., *dog*, *book*), and mispronunciations of familiar words that altered only the first consonant (e.g., "*bog*", "*dook*"). The patterns of brain activity revealed that 14-month-olds treated the known words and mispronunciations similarly, but reacted differently to the novel words. However, 20-month-olds treated the mispronunciations like novel words. The authors concluded that vocabulary development is important for infant's ease of access to phonetic detail.

Based on the changes in learning from 14 to 20 months, Werker et al. (2002) proposed that there is a period of development during which infants lack the capacity to attend to phonetic detail in word learning. After infants become capable of learning arbitrary word-object associations, but before they become proficient word learners, infants' computational resources may be expended by the processing demands of attending to the link between a sound form and its referent. There are not sufficient resources remaining to attend to phonetic detail. Werker and colleagues (Fennell & Werker, 2003a; Werker et al., 2002; Werker & Fennell, 2004) proposed that the apparent discontinuity in young infants' discrimination skills and later learning of phonetically similar words is due to this temporary lack of resources in unskilled word learners, not a qualitative change in phonetic representations. This explanation contrasts with the holistic representation account, which assumes discontinuity in the precise acoustic analysis performed in discrimination tasks versus the global representations used in lexical tasks (e.g., Jusczyk, 1992; Walley, 1993). The resource limitation account is based on the assumption that when confronted with any difficult task, "something has to give" (Fennell & Werker, 2003a, p. 249). In word learning, phonetic detail is sacrificed in favor of attending to the sound-meaning association, which is more essential to the immediate task of word learning.

Werker et al. (2002) investigated the relation between vocabulary size and the ability to learn phonetically similar words. They found a significant positive correlation between word-object association task performance and vocabulary size (productive and receptive) for 14-month-olds. Infants with larger switch versus same trial looking time differences tended to have larger vocabularies. At 17 months, the correlation between receptive vocabulary and magnitude of looking time difference showed a trend towards significance; at 20 months, the correlations were no longer significant. In exploring the changing pattern of correlations, Werker et al. (2002) found threshold vocabulary sizes for successful learning of the similar sounding labels: children with 25 or more words in their productive vocabulary or 200 or more words in their receptive vocabulary were more likely to exhibit learning in the laboratory task.

Both the holistic representation and resource limitation accounts predict vocabulary size effects on learning of phonetically similar labels. However, the role ascribed to vocabulary development differs. According to a holistic representation account (e.g., Charles-Luce & Luce, 1990, 1995; Walley, 1993), the vocabulary size threshold may indicate the point at which infants' lexicons become sufficiently crowded that they must reorganize and elaborate previously underspecified representations. However, Werker et al. (2002) proposed that without direct evidence of a causal effect of vocabulary development, "it is more prudent to assume the threshold is not absolute, but is merely an index of relative word-learning ability" (p. 22). According to the resource limitation account, children who are better word learners, as indexed by larger vocabulary size, find learning links between sound and meaning less taxing. Therefore, they have more resources available to process phonetic detail than less skilled word learners.

Werker and colleagues have sought evidence in support of the resource limitation account that is inconsistent with the notion of holistic lexical representations. This has proven difficult because the two proposals can often explain the same data (i.e., younger infants have more difficulty learning similar sounding words, the relation between word learning and vocabulary size). The resource limitation account predicts that if the word learning task is simplified, younger infants should be able to express their knowledge of phonetic contrasts. The holistic representation account holds that infants do not have access to phonetic details that have not yet emerged from vocabulary growth. In previous experiments, Werker and colleagues (Pater et al., 2004; Werker et al., 2002) attempted to reduce the demands of the task (longer exposure, more physically dissimilar objects, labels differing in more phonetic features), but were unable to improve the performance of 14-month-olds. However, Fennell (2004; personal communication) attempted to reduce computational demands by providing infants with prior experience with the novel objects used in the word-object association task. A group of infants received a novel (unnamed) toy to play with at home for six to eight weeks. Following the at-home exposure, infants were brought to the lab and habituated to the object associated with a label (e.g., "*din*"). The infants were then tested to examine whether they would dishabituate when a phonetically similar novel label was presented with the object (e.g., "*gin*"). A control group received no at home experience with the toy; these infants were first exposed to the toys as pictures in the word-object association task. Only children in the toy exposure group dishabituated, indicating that they noticed the change in the label. The holistic representation hypothesis cannot readily explain the finding that extra experience with an object can facilitate infants' access to phonetic detail.

In summary, Werker and colleagues' resource limitation account contends that the representations used for phonetic perception form the basis for word learning, but that infants' ability to use phonetic detail is limited by their computational capacity. This explanation differs from proposals of authors such as Walley (1993) and Charles-Luce and Luce (1990,1995), who argued that children begin with holistic lexical representations and build specified representations of words as a function of vocabulary development. What remains to be explained by the resource limitation hypothesis is a precise understanding of the capacity that is lacking in younger infants, and what changes between 14 and 17 months to enable infants to attend to the detail in new words. As we discuss later, Werker and Curtin (2005) have provided a new model for understanding the phonetic specificity in infant word learning that attempts to integrate infant word learning with studies of detail in infant word recognition.

B. Phonetic detail in word recognition

Evidence from studies of infant word recognition indicates that infants' apparent lack of attention to phonetic detail in word learning tasks may not apply to on-line recognition of known words (Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998; Fernald, Swingley, & Pinto, 2001; Swingley, 2003; Swingley & Aslin, 2000, 2002). In particular, studies probing children's representations of newly taught words may underestimate children's representational capacities. To test this hypothesis, Swingley and Aslin (2000) used a visual fixation paradigm designed to examine the time-course of young children's word recognition. This procedure is based on the natural tendency to look towards an object when hearing its name. Children's eye movements are monitored as they view two familiar objects (e.g., ball and shoe) and then hear a sentence containing a spoken target word (e.g., "Where's the ball?"). This task provides two gauges of word recognition: *accuracy*, or the duration of looking to the target relative to the distracter object, and *latency*, or how quickly the child switches gaze to the target object when initially focused on the distracter.

Studies using this paradigm have revealed rapid changes in young children's ability to recognize words: at 15 months, infants orient to a target picture just after hearing its entire label, and by 24 months, young children look to the appropriate picture before the completion of its label (Fernald et al., 1998). At 18 months, infants recognize words based on partial information (the first 300 msec of a word) as reliably as when hearing the entire word (Fernald et al., 2001). Thus, before the end of the second year, children are able to process word forms incrementally, as is characteristic of adult word recognition. This finding contradicts the claim that children begin to recognize words from partial information only after developing a substantial vocabulary (e.g., Walley, 1993).

Swingley and Aslin (2000) have further investigated the specificity of young children's lexical representations by adding a mispronunciation detection component to the visual fixation task. The basis of the mispronunciation task is that if children's lexical representations are holistic, their processing should not be disrupted by small changes in word forms. In contrast, if children's representations contain fine-grained detail, it should be harder to recognize the mispronounced words. Swingley and Aslin tested 18- to 23-month-olds' ability to recognize known words (based on parental report) when presented with correct pronunciations of the target words and mispronunciations. Children viewed two pictures on a large computer screen (e.g., baby and dog). They then heard a sentence containing either a correct pronunciation of the target word ("Where's the baby?") or a mispronunciation ("Where's the *vaby*?"). The test included a mix of consonant and vowel mispronunciations, as well as word-initial and word-internal mispronunciations.

Swingley and Aslin (2000) found that children were most accurate when hearing the correct pronunciations; children looked longer to the target objects after hearing a correct pronunciation rather than a mispronunciation. Looking accuracy was above chance for both pronunciations, indicating that children were still able to recognize the mispronounced words, albeit with more difficulty. Looking latency was also affected; children were slower to look to the target object after hearing a mispronunciation. These findings have been extended to children learning another language (Dutch) and mispronunciations using both common and rare sound substitutions (Swingley, 2003). The accuracy and latency results suggest that although mispronunciations still activate semantic knowledge of the known words, children's lexical representations are sufficiently detailed that word recognition is hindered by slight changes in pronunciation.

Swingley and Aslin's (2000) data could also support some versions of the holistic representation view, as many 18- to 23-month-olds have experienced a vocabulary spurt (Bates et al., 1995). However, Swingley and Aslin (2002) provided further support for early detail in known words by testing 14- to 15-month-olds in the mispronunciation detection task. They found that well before the vocabulary spurt, infants' word recognition was disrupted by mispronunciations of known words, both for close mispronunciations (e.g. "*vaby"* for baby) and more distant mispronunciations (e.g. "*raby"* for baby). Furthermore, according to parental report of receptive vocabulary, none of the infants knew any phonological neighbors for half of the words tested, and receptive vocabulary size was uncorrelated with the magnitude of the effect of mispronunciations on word recognition. These data indicate that crowding of vocabulary is not necessary for the development of fine-grained phonetic detail in lexical representations.

However, the words children *understand* may differ considerably from the word forms with which they are familiar. Well before infants produce or understand many words, they are extracting and storing word forms as they segment words from fluent speech, or hear words spoken in isolation. Word forms that are familiar, but are not yet associated with meanings, may well act as neighbors to the target words. To address this issue, Swingley (2003) extended his analysis of phonological neighborhood effects by examining a corpus of infant-directed speech to identify frequently occurring word forms that could potentially act as neighbors to the test items. His analysis indicated that infants were unlikely to have previously stored phonological neighbors of the correctly pronounced and mispronounced word forms tested. In this regard, Swingley's analysis yielded findings similar to those of Charles-Luce and Luce (1995)—infants were unlikely to know many similar sounding words. However, infants' successful detection of mispronunciations is inconsistent with the contention that early lexical representations do not contain more detail than is necessary to discriminate word forms, and that phonological neighbors are necessary for the development of specified lexical representations (Charles-Luce & Luce, 1990; Jusczyk, 1993; Metsala, 1997). Swingley and Aslin (2002) suggested that their results support the notion of developmental continuity of speech representations, such that the phonetic categories infants learn in the first year provide the basis for word recognition.

The apparently sophisticated word recognition skills of 14-month-olds reported by Swingley and Aslin (2002) raise the question of why infants the same age in Werker and colleagues' (Stager & Werker, 1997; Werker et al., 2002) task seem to be incapable of noticing alterations to words. The difference in performance may be due in part to the difference in the status of the words used. Swingley and Aslin tested infants' recognition of known words and Stager and Werker tested knowledge of recently experienced words. Using a habituation task similar to the original Stager and Werker (1997) task, Fennell and Werker (2003a) found that infants could detect violations in word-object combinations for similar sounding *known* words, specifically "ball" and "doll." [1] Fennell and Werker (2003b) also found that infants reported to understand the word "doll" and infants who did not explicitly have "doll" in their receptive vocabularies (but were probably familiar with it because of its frequency in child-directed speech) detected the mispronunciation of "doll" ("*goll*") in a habituation task. Similarly, Swingley (2002; described in more detail later) found that when infants were familiarized with a word form such as "*tiebie*" several times before it was used to label a novel object, the infants did not treat a highly similar mispronunciation of the label (e.g., "*kiebie*") like a request for the labeled target object. Infants who were not first familiarized with "*tiebie*" failed to notice the change. Thus, familiarity with a word, even without knowing the word's meaning, seems to facilitate attention to phonetic detail.

Fennell and Werker (2003a, b) proposed that infants are able to detect detail in familiar words because the familiarity reduces the processing load. Infants no longer have to attend to the formation of a link between sound and meaning and can devote more attention to the details of the word form. Alternatively, Swingley (2003) indicated that infants engaged in word learning may initially perceive speech appropriately, but that information is not encoded robustly—the sounds of the new word are not represented in memory in a way that can support word recognition. Failure to store a word form appropriately is not a difficulty limited to novice word learners; adults sometimes encode words with errors as well. Swingley (2003) added that it is unclear why 14-month-olds fail to robustly encode a new word after hearing it up to 100 times, but pointed out that the notion that learning of new words occurs gradually, especially for young infants, is not surprising. Many characteristics of natural word learning contexts may promote better learning than lab tasks, such as exposure to multiple exemplars of the object, or distributed learning occasions rather than the concentrated exposure that occurs in experimental tasks. In addition, variability in teaching contexts can facilitate learning (e.g., Lively, Logan, & Pisoni, 1993). Perhaps variability in speakers or labeling contexts is critical in helping infants to learn which variations are important (e.g., phonemic change) and which do not matter and should be ignored (e.g., speaker change).

Another important difference between the word learning studies (e.g., Stager & Werker, 1997) and word recognition studies (e.g., Swingley & Aslin, 2002) is methodological. In the word-object association task, failure to learn is expressed as failure to dishabituate on test trials presenting novel pairings of familiar words and objects. As Swingley and Aslin (2002, 2005) have suggested, infants' failure to dishabituate may not always be caused by a lack of learning, but may occur because the mismatching label is similar enough to the correct label to activate knowledge of the correct label and its referent. This possibility is analogous to infants looking to the picture of the baby after hearing "*vaby*" in the visual fixation procedure. Perhaps the visual fixation task is more sensitive because it is less susceptible to interference than the word-object association task. In the visual fixation task, infants can listen and seek the correct referent for a word, and have the opportunity to reject a referent that may be close, but not as good a match as the correct referent.

Ballem and Plunkett (2005) used the visual fixation method to examine the detail in 14-month-olds' representations of newly learned versus familiar words (see also Bailey & Plunkett, 2002, for similar work with 18- to 24-month-olds). Ballem and Plunkett's predictions were based on the consistent finding that 14-month-olds fail to notice detail in new words in the word-object association task (e.g., Stager & Werker, 1997), but notice detail in familiar words in both habituation and visual fixation tasks (Fennell & Werker, 2003; Swingley & Aslin, 2002). Thus, they predicted that infants would notice mispronunciations of known words ("ball" and "cup") but not newly learned words ("*tuke*" and "*vope*") taught during the experiment.

Surprisingly, there was some evidence of phonetic detail in both the familiar and novel words: infants showed systematic looking to the target objects given correct pronunciations of both familiar and new words. Infants did not look consistently to the target object following mispronunciations of either word type. However, infants' responses to the known words differed from their responses to new words. Although the infants did look systematically to correct pronunciations and *not* incorrect pronunciations of the novel words, the looking patterns of the correct and incorrect pronunciations did not differ significantly. Ballem and Plunkett contended that this is because newly learned word representations remain fragile. The infants have sufficiently detailed representations of the new words for the mispronunciation to disrupt recognition, but the difference in recognition for correct versus incorrect pronunciations is weaker than for familiar words.

Ballem and Plunkett's (2005) experiment suggests that although familiarity likely does play a role in infants' word recognition (as it does for adults), high familiarity does not seem to be essential for infants' representation of phonetic detail. The findings also indicate that the task demands of the visual fixation task may be crucial in revealing this detail, a proposal that merits further investigation. When 14-month-olds are required to react to a minor change in a highly familiarized word, as in habituation-based tasks, they do not show evidence of noticing phonetic detail. Although habituation-based tasks involve minimal demands on coordination and production, the testing conditions may not be ideal for expressing knowledge of phonetic detail—the objects and labels presented during testing are highly familiar, the only change is in their pairing. Thus, the conditions of same and switch test trials may differ sufficiently to spark an increase in interest, or can only do so for older infants who are highly sensitive to the change. In contrast, in visual fixation tasks, perhaps 14-month-olds are not easily misled by an altered pronunciation when required to look to a named object; the change may be noticed with little difficulty. This measure may be more revealing of their representations of fine-grained word form characteristics.

As this review has shown, the findings from studies of phonetic detail in early lexical representations are complex. When words are familiar, novice word learners show attention to detail in both habituation-based (Fennell 2004, personal communication; Fennell & Werker, 2003a, b) and visual fixation tasks (Swingley & Aslin, 2002). But when words are novel, infants seem not to notice detail in habituation tasks (Stager & Werker, 1997), but may notice some detail in visual fixation tasks (Ballem & Plunkett, 2005).

Werker and Curtin (2005) presented a new framework for understanding the seemingly discrepant patterns in infant speech perception and early word learning and recognition.

PRIMIR, Processing Rich Information from Multidimensional Interactive Representations, attempts to explain why infants use detailed phonetic information (e.g., McMurray & Aslin, 2005) and indexical information (such as speaker identity and affect; e.g., Houston & Jusczyk, 2000; Singh, Morgan, & White, 2004) in some tasks, but in other tasks, they seem to attend to higher level categorical and word-level properties (e.g., Jusczyk & Aslin, 1995).

According to PRIMIR, infants' difficulty processing the phonetic detail of new words comes from the demands of attending to the relevant information that makes words distinct. The features of word forms are appropriately represented based on a general perceptual analysis. However, when the words being examined overlap a great deal (as with "*bih*" and "*dih*"), infants may not know what information is criterial for distinguishing these forms, making it very difficult to attend to the sound-meaning linkage. As children learn words, the overlap in sound characteristics of the word forms increases and categories of phonemes eventually emerge from the regularities in the overlapping words. In this way, PRIMIR places more emphasis on the role of vocabulary development in infants' ability to access phonetic detail than Werker and colleagues' (e.g., Werker et al., 2002) earlier resource limitation account.

Werker and Curtin proposed that the acquisition of a critical number of form-meaning associations is necessary for phonemic categories to develop, and that categories should emerge earliest from dense phonological neighborhoods (a proposal that is similar to those made by Walley, 1993 and Charles-Luce & Luce 1990, 1995). After phonemic categories have emerged, children approach word learning with an idea of which sound distinctions are essential to word form identity, leaving more resources remaining for associating forms with meanings. At this point, children can learn words readily and flexibly in a variety of tasks (see Werker & Curtin, 2005, for a more thorough explanation of this process).

Thiessen (2005) has also addressed how infants develop the skills necessary to access phonetic detail in new words. He investigated the contribution of learning about the functional significance of phonetic distinctions. Thiessen pointed out that infants can often *detect* differences that they appear to not yet know how to *use*. For example, although 2-month-olds can discriminate between stressed and unstressed syllables (Turk, Jusczyk, & Gerken, 1995), infants do not use this cue to segment words until 8 months of age (Jusczyk, Houston et al., 1999). Thiessen and Saffran (2003) proposed that infants must learn where stress falls within words in their native language in order to use stress as a segmentation cue. Similarly, although 14-month-olds may be able to distinguish between phonetically similar word forms like "*bih*" and "*dih*," they have to learn that the difference between "/b/" and "/d/" indicates a difference in word meaning in order to use this information in word learning tasks. Infants may need to learn the distributional contexts of speech sounds as they occur in different words in order to learn how to use the perceptual distinctions. Thiessen (2005) proposed that because older infants know more words than younger infants, they may have gathered more distributional information about how phonetic distinctions function in their language.

Thiessen's distributional account and PRIMIR (Werker & Curtin, 2005) both suggest that although infants may perceive phonetic distinctions appropriately, they do not always know to treat the distinctions. However, Thiessen's perspective on the role of vocabulary development is somewhat different from the claim presented in PRIMIR, though the two are not necessarily mutually exclusive. Werker and Curtin emphasized the role of overlapping word forms and indicated that learning clusters of words in dense neighborhoods should promote the development of phonemic categories. Thiessen emphasized that learning how phonemes pattern in *different* contexts is key.

The distributional account specifically predicts that when infants have experience with phonemes in different lexical contexts, they should no longer confuse minimal pair words that differ on that phonemic contrast. To investigate this hypothesis, Thiessen used the word-object association task (e.g., Stager & Werker, 1997) to test whether experience with the phonemes /d/ and /t/, presented in different lexical contexts, would enable 15-month-olds to pick up on phonetic detail in a new word. Infants habituated to three word-object combinations: a "*daw*" object, a "*dawbow*" object, and a "*tawgoo*" object to provide lexical contexts for /d/ and /t/. Infants' looking time was then compared for trials in which the daw-object was presented with the label "*daw*" (same) and with the label "*taw*" (switch). Consistent with the distributional account, infants did not treat the labels interchangeably; they dishabituated when the daw-object was labeled with "*taw.*" To ensure the facilitation was not caused by reduced attentional capacity demands from hearing the "*daw*" in "*dawgoo*", Thiessen presented another group of infants with the object labels "*tawgoo*" and "*dawgoo,*" in addition to "*daw*". This set of word-object combinations provides less distributional information than "*dawbow*" and "*tawgoo*", as /d/ and /t/ are now in the same phonological context— "-*awgoo*". As predicted, infants now treated "*taw*" and "*daw*" as interchangeable.

Thus, when 15-month-olds experienced speech sounds occurring in different lexical contexts (that is, associated with different objects and in different phoneme combinations), they noticed subtle phonetic differences in novel words. The manipulation of infants' experiences with distributions of lexical contexts may provide a model of what occurs between 14- and 17-months to facilitate learning of phonetically similar words. Thiessen suggested that older infants have learned about the contexts in which phonetic distinctions occur and know which distinctions signal differences in meaning—they have learned which distinctions have functional significance. This process may occur at a different pace for different speech sounds depending on the order in which infants become familiar with clusters of words, a suggestion also proposed in other models (e.g., Walley, 1993; Werker & Curtin, 2005).

Many accounts of the development of phonetic detail hypothesize an important role for vocabulary development. To test the roles of neighborhood density and other types of clusters (i.e., words beginning with the same phoneme) in word learning and phonological development, it will be important to examine how the distinctions that infants are sensitive to in word learning relate to the constellations of words in infants' developing lexicons. It may be particularly important to consider how attention to phonetic detail is influenced by both distributional information from words stored with meanings (i.e., in receptive vocabulary) and without meanings (i.e., words that have been segmented but not yet paired with meanings), as these two types of experiences may not have equivalent effects on the acquisition of new words.

What conclusions can we draw about the nature of early lexical representations from the study of phonetic specificity? First, children's representations of words are more detailed than thought previously (reviewed in Walley, 1993). The use of familiar words and sensitive measures of learning and recognition have revealed sophisticated processing of spoken words in young children. Second, well-developed vocabularies and crowded phonological neighborhoods are not essential for forming fine-grained lexical representations. The evidence of detailed representations in novice word learners (Ballem & Plunkett, 2005; Swingley & Aslin, 2002) does not indicate, however, that vocabulary growth and increasingly dense phonological neighborhoods do not affect how words are represented. Clearly, phonological development continues well past the second year and is shaped by the words children hear and learn (e.g., Beckman & Edwards, 2000; Edwards, Beckman, & Munson, 2004). Neighborhood density also affects language processing in later childhood and adulthood (Garlock, Walley, & Metsala, 2001; Vitevitch & Luce, 1998), and likely affects changes in lexical representations, particularly during periods of rapid vocabulary growth. In addition, experiments by Thiessen (2005) suggest that learning constellations of words that overlap in other ways (e.g., words beginning with /b/) may also affect the use of phonetic detail in word learning.

A third conclusion is that the evidence supporting developmental continuity in the representations of speech sounds. The phonetic distinctions infants learn in the first year provide a foundation for the representations of early words. This is good news for many researchers, as this conclusion helps to maintain the relevance of studies of infant speech perception. However, how infants transition from difficulty with the specificity of new words to ease in noticing detail remains mysterious. Based on comparisons of habituation-based (Stager & Werker, 1997) and visual fixation procedures (Ballem & Plunkett, 2005), the task in which learning is measured seems important. Additional demonstrations of the importance of how specificity is examined have come from Vihman et al. (2004) and Swingley's (2005a) studies further examining the findings of Hallé and de Boysson Bardies (1995). In contrast to the original results, Vihman et al. and Swingley have both shown that infants *do* detect alterations of familiar words presented in lists, in particular when one considers the effects of learning that occurs within the task and of making changes at different word positions. Other findings also suggest that vocabulary development (Werker et al., 2002; see also Edwards et al., 2004) and familiarity with word forms (Fennell & Werker, 2004) matter for infants' ability to recognize alterations to words. However, the precise role that vocabulary development plays, and whether the influence of extant vocabulary is based on neighborhood density or some other type of vocabulary clustering, remains unclear. The effect of familiarity of sound sequences is also not well understood; it may not be as essential to noticing detail as was once suggested (Ballem & Plunkett, 2005).

A final conclusion is that the study of phonetic specificity in early lexical representations has implications for understanding how the lexicon develops more generally. For example, the results of this body of work suggest that there may be changes in speed of processing and accuracy of word recognition depending on the amount of experience a child has had with a particular word. How rapidly lexical representations change from acting like new words to acting like well-known words may also change with development. This change may be part of what makes older infants better word learners—their new words may become integrated with the existing lexicon and become "familiar" more readily than for younger infants. Studies of phonetic specificity have generated sensitive measures of word learning and recognition that can be extended to the exploration of other connections between how infants learn about sound structure and the mapping of those sounds to meanings.

IV. Effects of familiarity with the sounds of words on word learning

In this section, we examine how infants' increasing familiarity with the sounds of the words in their native language lays a foundation for word learning. Specifically, we ask how learning about patterns of sound combinations in words (phonotactic probability) and overlapping word forms (neighborhood density) affect infants' ability to learn new words. We then discuss how infants' ability to segment words from fluent speech influences how words are mapped to meaning. Although the processes by which familiarity with sounds of words affects early word learning are not yet well understood, it promises to be a fruitful and revealing area of study.

A. Phonotactic probability and neighborhood density in early word learning

Infants develop remarkable sensitivities to the patterns of sound combinations in their native language long before they understand many of the words they hear. The ability to track distributional information about sound sequences is available early in life (Chambers, Onishi, & Fisher, 2003; Saffran et al., 1996; Saffran & Thiessen, 2003) and is maintained through adulthood (Onishi, Chambers, & Fisher, 2002; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). By 9 months of age, infants prefer to listen to words that fit the typical patterns of phoneme combinations of their native language (Jusczyk, Luce, & Charles-Luce, 1994). Regularities in the sound combinations of words affect the speed and accuracy of word recognition in older children and adults (Gathercole, Frankish, Pickering, & Peaker, 1999; Onishi et al., 2002; Vitevitch, Luce, Pisoni, & Auer, 1999). Thus, characteristics of the sound structure of words affect processing throughout life. Although the development of semantic representations must be very influential in word learning, characteristics of phoneme combinations likely affect how new words are added to the lexicon as well.

The connection between sound patterns and mapping to meaning has been investigated in only a handful of studies of early word learning. Research examining how learning about sound combinations affects word learning has primarily addressed two interrelated characteristics of sound structure: phonological neighborhood density and phonotactic probability. As described previously, a word's phonological neighborhood includes all of the words that differ from a given word by one phoneme deletion, substitution, or addition in any position in the word. Words that overlap with many other words are said to reside in dense neighborhoods; words with few neighbors reside in sparse neighborhoods. Phonotactic probability refers to the probability that a phoneme or phoneme combination occurs in a given position in words and syllables.

Neighborhood density and phonotactic probability are highly correlated—words in high density neighborhoods tend to consist of high frequency phoneme combinations.

However, neighborhood density and phonotactic probability have differential effects on lexical processing. Studies of adult word recognition have shown that nonwords consisting of high phonotactic probability sequences are repeated faster than nonwords with low probability sequences (Vitevitch & Luce, 1998; but see the debate in Lipinksi & Gupta, 2005 and Vitevitch & Luce, 2005). Children are able to repeat high probability nonwords with better accuracy than low probability items (e.g., Edwards, et al., 2004; Gathercole, 1995) and show greater recall of lists of high probability nonwords (Gathercole et al., 1999). Even young children (2 1/2 years of age) are sensitive to phoneme frequencies in nonword repetition (Coady & Aslin, 2004).

The neighborhood density of real words seems to have an opposite effect; words from dense neighborhoods are recognized more slowly and less accurately than words from sparse neighborhoods (Vitevitch & Luce, 1998). Children also require more sound information to recognize words from dense neighborhoods than sparse neighborhoods, and are less accurate at repeating words from dense neighborhoods (Garlock et al., 2001; Metsala, 1997). These findings support the notion that the lexicon is organized such that similar sounding words compete for activation. Thus, high neighborhood density hinders rapid word recognition for items established in the lexicon, whereas high phonotactic probability facilitates the processing of nonwords that have not been stored previously.

It is not yet clear how knowledge of phonotactic probabilities and the neighborhood density of the early lexicon affect the formation of new sound-meaning associations. In describing the effects of phonotactic probability on nonword repetition performance, Edwards et al. (2004) explained that novel words containing common sound patterns may have the support of familiar words that can be "used by analogy" in the development of acoustic and articulatory representations (p. 433). Similarly, in word learning, children may be able to add familiar sounding, high phonotactic probability words to the lexicon more readily than words consisting of unusual sound sequences with low probability. High probability sequences consist of phoneme combinations that the infant has experienced frequently in the past; the sounds are connected by well traveled pathways. These word forms may be easier to encode than low probability words, allowing the infant to focus on establishing the link between the form and its meaning. Higher probability sequences may also be easier to recall, making it more likely that the infant will remember the word form and its associated referent when recognition is required. Easily-acquired and early-acquired words may tend to consist of high probability sound sequences.

Alternatively, for new word forms that are similar to previously stored words, establishing the appropriate association between sound and meaning may be difficult. This is related to the effect of neighborhood density: if the infant has already established a dense phonological neighborhood, linking meaning to a new word in this neighborhood may be difficult because the word can be confused with several other words. High density could also impair recognition and comprehension of a new word, as attempting to recall the target word could activate similar sounding words. The representation of the target word may not be sufficiently well-developed to win the competition for activation. By this reasoning, in early vocabulary development, children may fill in the lexicon by acquiring words in sparse neighborhoods more readily than those in dense neighborhoods.

In the literature investigating how knowledge of sound combinations might affect word learning, phonotactic probability and neighborhood density are sometimes considered independently (Hollich et al., 2002), and are sometimes correlated as in natural language (Storkel, 2001, 2004a). It is not clear whether there are independent effects of phonotactic probability and neighborhood density in early word learning, as there are for adults in some cases (i.e., words versus nonwords). The existing developmental research indicates that prior knowledge of word forms and sound combinations affects how new words are added to the lexicon, but many of the details of this influence have yet to be tested.

To examine whether infants and young children tend to acquire words in dense or sparse phonological neighborhoods, Storkel (2004a) analyzed the age of acquisition for nouns on the MacArthur Communicative Development Inventory (CDI), a parental report measure of vocabulary for infants (8-16 months, Words and Gestures version) and toddlers (16-30 months, Words and Sentences version). Early-acquired words tended to reside in high-density neighborhoods, particularly for short and low frequency words. Later acquired words tended to come from sparse neighborhoods. The effects of neighborhood density on age of acquisition were reduced for high frequency words, perhaps because high exposure rates outweighed the effects of sparse neighborhoods. Storkel proposed that fitting a new word into an established neighborhood may strengthen its representation, making it learnable with fewer exposures compared to new words that are dissimilar from known words. Storkel's findings also suggest that specification of word forms must occur at a younger age than previously supposed (Charles-Luce & Luce, 1990, 1995).

Coady and Aslin (2003) attempted to improve upon previous analyses of children's vocabularies by using more representative speech samples, and by including both maternal input and children's productive vocabulary in their neighborhood analysis. They also examined neighborhood density weighted by both neighborhood frequency and by vocabulary size, to ensure that differences in density were not solely attributable to differences in the number of words in children's versus adults' lexicons. They found that children's vocabularies consisted of sparser neighborhoods than those of adults, a finding consistent with previous analyses. However, the neighborhoods were substantially denser than previous analyses reported (Charles-Luce & Luce, 1990, 1995); words in children's productive vocabularies had an average of 6.5 neighbors at age 3 1/2. Children also tended to know a greater proportion of shorter words than longer words, and shorter words overall are from higher density neighborhoods. In addition, when vocabulary size was controlled, children were found to have a greater proportion of confusable words than adults. Coady and Aslin (2003) concluded that children learn words with frequent sounds and sound combinations earlier than words with less frequent sounds. Their analyses also support the notion that children maintain detailed lexical representations early in life. If children did not represent phonetic detail in their early words, one would expect them to add dissimilar words to the vocabulary earlier than similar sounding words in order to maintain non-overlapping lexical entries.

The findings from Storkel's (2004a) and Coady and Aslin's (2003) analyses lend support to the idea that characteristics of word forms play a role in how items are added to the lexicon and that children are not reluctant to incorporate overlapping word forms into their vocabularies. However, Coady and Aslin (2003) acknowledged limits to the conclusions that can be drawn from their analyses. The analyses contain a great deal of information, but they still represent vocabulary at one moment in time, rather than as a changing system. They cannot reveal how new items are added to the lexicon. This is also true of Storkel's analysis of group age of acquisition trends. To more directly test the notion that children add new words to dense phonological neighborhoods early in word learning, it will be important to examine changes in the vocabulary constellations of individual children.

Vocabulary analyses also cannot reveal how readily words with different degrees of overlap with known words are added to the lexicon when those new words are first encountered. Swingley and Aslin (2005) performed a set of experiments to examine the effects of phonological neighbors on 18-month-olds' learning of new words. They proposed that the novel neighbor of a familiar word (e.g., "*tog*") may be sufficient to activate the representation of the known word ("dog"), although the exact match of the familiar word form would likely produce greater activation of it than the novel neighbor (see also Swingley & Aslin, 2002). However, knowledge of stored lexical items may interact with the output of phonological processing indicating that the novel neighbor is a new and different word form. Swingley and Aslin compared infants' performance learning novel neighbors of known words (e.g., "*tog*") and novel non-neighbors (e.g., "*meb*") as object labels in a visual fixation paradigm. They investigated whether infants would tend to be open to adding new words to the lexicon, readily treating both the novel neighbors and the novel non-neighbors as labels for novel objects. Alternatively, infants might be conservative word learners, treating the novel neighbors as instances of the known words. In this case, infants should be reluctant to map the neighbor labels to objects.

In the first experiment, Swingley and Aslin found that when infants were taught both a novel neighbor and a non-neighbor label and tested with both novel objects, they only looked consistently to the correct target when the non-neighbor was requested. However, when the neighbor object (the "tog) was presented with its associated familiar object (the "dog"), infants looked appropriately to the target neighbor object. Thus, children appeared to learn something about the neighbor label (enough to know that it did not refer to a dog, for example), but learning was more robust for non-neighbor labels.

In a second experiment, Swingley and Aslin taught one group of infants one novel neighbor object label and another group one novel non-neighbor label to reduce the demands of attending to multiple objects and labels. Again, only children taught non-neighbor labels looked consistently at the requested target object when the two novel objects were presented (the target and a second novel object that was introduced, but not labeled, during teaching of the target). Interestingly, when the labeled neighbor object was presented with its associated familiar object, infants failed to look consistently at the requested neighbor object (e.g., "tog") or the requested familiar object (e.g., "dog").[2] Infants who were not taught neighbor labels readily recognized the familiar words. Thus, infants' recognition of known words was disrupted after being taught a similar sounding object label. The findings of the second experiment indicate that infants learned something about the novel neighbor labels; however, the nature of what they learned is again unclear. Similar to the first experiment, infants seem to have learned enough to know that they should not treat the label ("tog") like a similar-sounding familiar word ("dog"), but not enough to identify the appropriate novel object the label was paired with.

Swingley and Aslin proposed that the locus of infants' difficulty learning neighbors of known words is in their ability to associate the word form with the meaning, and not in the perceptual analysis of the word form. They suggested that interference caused by similar sounding words makes it difficult for young children to learn words that are phonological neighbors. Hearing a novel neighbor word form, even if it is not an exact match to a known word form, may activate the known word's meaning. This may disrupt the infant's ability to associate a new meaning with the novel word. The interference explanation may have implications for understanding 14-month-olds' difficulty learning two novel similar sounding words, as in Stager and Werker's (1997) experiments. Activation of the two novel forms may cause problems for infants' ability to attend to the form-meaning association for either word. In addition, during testing, hearing one word may activate the other word as well, making the detection of a mismatch difficult.[3]

Hollich and colleagues (2002) tested whether neighborhood density affects infants' learning of new words by manipulating infants' experience with the phonological neighbors of new words, rather than relying on infants' native-language experience. In this experiment, 17-month-olds were familiarized with repetitions of two novel word lists: a high density list containing 12 neighbors of the novel word "*tirb*," (differing only in the initial consonant) and a low density list consisting of three neighbors of the word "*pawch*" plus nine filler items. Using the visual fixation paradigm, the infants were then presented with two novel objects labeled with the words "*tirb*" and "*pawch*." Critically, the infants had not heard these items during familiarization. Infants only showed evidence of learning the low density item, looking longer to the "*pawch*." This suggests that infants learned the low density, and possibly less confusable, item more readily, a findings that seems consistent with Swingley and Aslin's (2005) experiment but inconsistent with the neighborhood density analyses of children's vocabularies (Coady & Aslin, 2003; Storkel, 2004a).

However, Hollich et al. (2002) also found that children in a control group with no previous exposure to either neighborhood had difficulty learning the labels. The authors performed a second experiment to directly test the idea that there is a "sweet spot" for word learning somewhere between starting fresh with a new word form and attempting to fit a new word into a crowded neighborhood. They found that exposing children to the high density word list only once, rather than six times as in the original experiment, facilitated learning of the novel label. This exposure provided the infants with enough familiarity with sound combinations similar to the novel label to facilitate learning without inducing competition and confusion.

Swingley and Aslin (2005) and Hollich et al.'s (2002) experiments demonstrated that infant learning about sound structure can affect how word forms are associated with objects. This broad conclusion is consistent with the findings of Coady and Aslin (2003) and Storkel's (2004a) vocabulary analyses. The finding that word form characteristics matter is noteworthy, as many other factors have the potential to influence the mapping of sound to meaning, such as frequency of exposure, salience of the labeled referent, salience of the label in the input, and social learning cues. However, the analyses and experimental findings conflict. In Swingley and Aslin and Hollich and colleagues' experiments, children have difficulty learning new words when they are potentially confusable with other familiar word forms. The vocabulary analyses indicate that children build the lexicon with words in neighborhoods that contain overlapping words. The difference may be attributable in part to the conditions of natural vocabulary learning, which may include repeated exposure in varied contexts and environmental and pragmatic support capable of overriding any confusion caused by similar sounding words. Perhaps facilitation of word learning in dense neighborhoods is difficult to demonstrate in experimental tasks because of the simplified word-learning environment commonly used.

As Coady and Aslin (2003) and Storkel (2004a) pointed out, the influence of neighborhood density may also be due in part to facilitative effects of phonotactic probability. Infants are very skilled at tracking distributional patterns and gathering knowledge of phonotactic probabilities during the first year of life. This learning is likely to transfer to the task of associating meanings with words. Hollich and colleagues provided some evidence for the role of phonotactic probabilities by showing that some familiarity with particular sound sequences facilitated word learning. However, we still know little about the role that natural phonotactic patterns play in infant word learning. Support for the influence of natural language phonotactic patterns on word learning comes from experiments with older children. Storkel (2001, 2003) found that for 3- to 6-year-old children, novel words consisting of common sound sequences were associated with meanings more readily than labels with rare sound sequences (but see also Storkel, 2004b). The type of distributional learning mechanism that tracks phonotactic probabilities is active throughout life (e.g., Chambers et al., 2003; Onishi et al., 2002). Such patterns would likely affect infant word learners as well. Highly probable phoneme sequences from the infants native language might be more readily encoded and remembered, facilitating links between sound and meaning. High probability sequences might also be more readily retrieved from the lexicon for recognition. This could be displayed in several ways: infants may be more accurate at identifying items with high probability labels; infants may recognize items more rapidly; infants may retain the association between a high probability word with its referent over a longer period of time than for a low probability word. These possibilities have yet to be explored.

B. Segmenting words and mapping sound to meaning

Most words that infants hear are not presented in isolation (Woodward & Aslin, 1990; Brent & Siskind, 2001). Therefore, infants' ability to associate meanings with words should be greatly facilitated by the ability to segment individual word forms from fluent speech. Infants learn a great deal about the sound structure of their language that helps them to find words in the speech stream. By the end of the first year, infants can take advantage of patterns of syllable co-occurrences (Saffran et al., 1996), rhythmic patterns (Johnson & Jusczyk, 2001; Jusczyk, Houston et al., 1999; Thiessen & Saffran, 2003), and regularities in the phonetic variations and phonotactic patterns that occur at the beginnings and ends of words (Jusczyk, Hohne et al., 1999; Mattys et al., 1999) Presumably, once the infant has segmented a word form, it is available to be associated with a meaning. However, we do not yet understand the nature of the connection between word segmentation and the ability to link meaning to words, both of which are essential skills for lexical development.

One feature of learning that might simplify this process is that some word forms may not require segmentation; that is, they may be presented to infants as words in isolation. However, although parents do present a minority of words this way—one estimate suggests 10% (Brent & Siskind, 2001)—parents more typically speak words within fluent utterances, even novel words that they are trying to teach their child (e.g., Woodward & Aslin, 1990). Some words are not spoken in isolation for grammatical or pragmatic reasons, for example parents are unlikely to present function words (“the”, “among”, “over”) as isolated words. A related problem is that when parents speak multisyllabic words in isolation, infants must somehow decide whether these utterances consist of a single multisyllabic word or multiple words. Infants need to make headway on the segmentation problem before word representations become available. After proto-words are segmented, these can play a key role in the segmentation of subsequent words (Bortfeld, Morgan, Golinkoff, & Rathbun, 2005). All of these considerations strongly suggest some sort of link between the mechanisms underlying segmentation from fluent speech and the emerging lexicon.

One way that the basic skills of segmenting and associating meanings with words may connect in vocabulary acquisition is that segmented sound sequences may be stored as potential words, waiting to be linked with meanings. Perhaps by the end of the first year, infants gather a rudimentary lexicon of segmented forms that have yet to be linked to referents. One of the factors preparing infants for building a productive and receptive lexicon may be the segmentation and storage of these word forms. Conversely, during the first year, infants likely gather concepts that are not yet associated with labels. Early word learning may be supported by the integration of previously gathered forms and conceptual representations. Thus, as infants begin to map meanings to words, they are not starting from scratch with each lexical item.

There may also be developmental changes that affect how rapidly these newly segmented words are available to be mapped to meaning. Younger infants may require more experience with the sounds of words before they can link sounds to referents; they may rely more on previously gathered segmented forms for word learning than older infants do. Older infants may be able to segment a word form on-line and immediately associate a meaning with it. Also, for infants at any developmental level, newly segmented words may require additional experiences in new contexts before they are available to be associated with referents.

One means of investigating the relation between segmentation and word learning is to start by understanding the nature of the representations that emerge from attempts to segment words. Despite the burgeoning literature on "word segmentation," little work has assessed the claim that what infants segment is actually represented as potential native language *words*, as opposed to familiar sound sequences unrelated to the lexicon. Saffran (2001) and Saffran and Wilson (2003) examined the representations yielded by statistical segmentation mechanisms. Infants are highly sensitive to distributional information, and can use patterns of syllable co-occurrences to segment words from fluent speech in artificial languages (Aslin et al., 1998; Saffran et al., 1996). However, we know less about the representations that emerge from such processing. Do infants interpret the sound sequences they are segmenting from speech as actual words, or instead as sound sequences that are probable in the native language? To test whether the output of infant statistical segmentation yields wordlike sequences, Saffran (2001) first exposed infants to an artificial language in which the only cue to word boundaries was the high transitional probabilities within words versus the low transitional probabilities across word boundaries. Infants were then tested using "words" and "part-words" (sequences crossing word boundaries) from the artificial language embedded within either English sentences or matched nonsense frames. Infants preferred to listen to words over part-words when they were embedded in English sentences, but not when the words and part-words were embedded in nonsense frames. The findings support the claim that infants segment wordlike sequences that are ready to be integrated with native language knowledge. Curtin, Mintz, and Christiansen (2005), using the same paradigm, extended these results to show that infants' representations of newly segmented words retain the stress patterns heard during exposure.

Moreover, newly segmented sound sequences appear to participate in subsequent aspects of language learning. Saffran and Wilson (2003) provided further support for the claim that "words" are the output of statistical segmentation by showing that infants can use the output of statistical segmentation in a grammar-learning task. Infants exposed to an artificial language were able to use syllable co-occurrences to segment words from the language, and then to discover a simple grammar that determined the legal orderings of those words. These findings support the hypothesis that statistical learning about syllable sequences yields representations that are word-like.

Swingley (2005b) investigated how infants' segmentation skills might relate to word learning by examining whether the sound sequences that are most likely to be segmented by infants actually correspond to real words. To do so, Swingley analyzed corpora of Dutch and

English infant-directed speech. The analysis complements Saffran's (2001) experiment by testing whether a statistical learning mechanism applied to natural speech input is likely to yield real words and not mis-segmentations. Swingley examined how infants might cluster sound sequences based on tracking the probability and frequency of syllable co-occurrences in infant-directed speech. The results suggest that if infants used such a mechanism, they would primarily extract real words. Swingley proposed that word segmentation provides infants with a "protolexicon" of word forms available to be mapped to meaning. The prior segmentation of a word form should make the mapping process easier because the infant no longer needs to figure out the sound form. Instead, the infant can concentrate on identifying the word's meaning, and linking the sound and meaning representations. Thus, a stock of candidate word forms may then become early-learned vocabulary items. Swingley's analysis illustrates the importance of considering what is likely to be stored in memory by infants in addition to what they are reported to actually understand. Segmented words encoded in memory may affect the association of sound and meaning, phonotactic probability and neighborhood density, and early syntax learning.

Hollich (in press) performed an experimental test of whether prior segmentation of a word form affects mapping to meaning by familiarizing 23-month-olds with a passage containing two target novel words. Children had the opportunity to segment the words from this speech stream before they were associated with novel objects. In this experiment, Hollich also examined whether children could generalize across speakers when mapping a segmented word to meaning. One of the novel words was presented by the same speaker during familiarization and labeling; the other novel word was presented by different speakers during familiarization and labeling. Hollich reported that children were better able to learn an object label that was a previously segmented word, demonstrating that prior experience with a word form rapidly facilitates the link between sound and meaning. However, there were limits on young children's ability to apply prior learning about the word form. When the speaker changed between the familiarization and labeling phases of the experiment, prior experience did not facilitate word learning, even for the relatively sophisticated word learners tested. This is likely due to the difficult learning task presented; the children heard the two new labels only six times each. In follow-up experiments, Hollich found that children could learn the words given more repetition and variability during labeling. Hollich's data demonstrates that 2-year-olds are still developing flexibility in lexical representations, particularly for newly presented words. When a learning task is difficult (i.e., few exposures), even practiced word learners may require prior experience with word forms to associate them with objects.

Swingley (2002) also found that prior segmentation of word forms facilitates the development of robust sound-meaning associations. Dutch 18- and 19-month-olds watched an animated movie that included several presentations of a novel word form embedded in sentences with no referent present. Half of the children then heard the same novel word used as an object label in a visual fixation task: "This is a *tiebie*" (translated from Dutch). The other half of the children heard an unfamiliarized word used as a label. Children then viewed two objects on a screen, the labeled object and a second novel object. They were then asked, "Can you find the *tiebie*?" with a correct pronunciation of the label or a phonetically similar mispronunciation (e.g. "*kiebie*"). Children who had the opportunity to segment the word prior to learning it as an object label showed a difference in looking behavior to the mispronunciation. Children who did not have previous experience with the word did not notice the mispronunciation. This experiment indicates that prior segmentation of a word form facilitates attention to phonetic detail in new words.

The data from Hollich (in press) and Swingley's (2002) studies demonstrate that segmentation of word forms affects how readily infants map sounds to meanings and attend to phonetic details in new words. Previous experience with a segmented word form can facilitate word learning even for skilled 2-year-old word learners. It is not yet clear how segmenting words and associating meanings with words are related for younger infants, who are likely still facing challenges in word segmentation. Younger infants may rely even more on prior word segmentation in order to learn new labels. Future experiments combining word segmentation tasks with word learning tasks hold promise for investigating how prior experience with word forms and gathering of a "proto-lexicon" may contribute to the rapid pace of vocabulary development during the second year of life.

V. Conclusions

A large body of literature has been dedicated to discovering the nature of the perceptual tuning and native-language knowledge acquired before infants begin to speak (reviewed in Aslin, Jusczyk, & Pisoni, 1998; Saffran, Werker, & Werner, in press). A separate literature explores how infants and young children focus their attention on the appropriate meanings in learning new words (e.g., Bloom, 2000; Markman 1990; Woodward & Markman, 1998). The connection between infants' learning about the sounds of their language and mapping those sounds to meanings presents a relatively new area of research. In this chapter, we have reviewed potentially important connections between learning how language sounds and learning what language means: phonetic specificity in early lexical development, and how familiarity with the sounds of words affects early word learning in areas of phonotactic probability and neighborhood density, and word segmentation. A general conclusion across the three areas of research reviewed here is that learning about the sound structure of the native language during the first year provides a critical foundation for later word learning. Furthermore, we suggest that the sound part of the sound-meaning mapping may be as important a determinant of learning as the meaning part. Although substantial additional research is needed, the sounds that make up the “wugs”, “blickets”, “tomas,” “daxes,” and “modis” used in decades of word learning research clearly do not come out of nowhere. The sounds of the words that infants are engaged in learning are intricately linked to extensive prior experience with the ambient language. By studying the acquisition of sounds and the acquisition of meanings in tandem, we may hope to reach a new level of insight into how infants accomplish the astonishing feat of learning words.

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Footnotes

1 In Western Canadian English, the dialect of the participants, "doll" and "ball" are minimal pairs.

2 The second experiment was conducted with Dutch learning infants, using Dutch words and their novel neighbors. We carried over the same dog/tog example for simplicity.

3 The interference explanation does not as readily explain why infants fail in the one-object version of the word-object association task (used in Pater et al., Stager & Werker, 1997, Experiment 2). However, a related proposal is that the elevated activation of the habituated word form (e.g., "bih") may drown out the activation of the overlapping novel form (e.g., "dih") and contribute to infant's failure to dishabituate.