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When Variability Matters More Than Meaning: The Effect of Lexical Forms on Use of Phonemic Contrasts

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During the first half of the 2nd year of life, infants struggle to use phonemic distinctions in label–object association tasks. Prior experiments have demonstrated that exposure to the phonemes in distinct lexical forms (e.g., */d/* and */t/* in *daddy* and *tiger*, respectively) facilitates infants' use of phonemic contrasts but also that they struggle to generalize the use of phonemic contrasts to novel syllabic contexts (Thiessen, 2007; Thiessen & Yee, 2010). Further, in prior research, infants have been provided only with experience in lexical forms that refer to novel objects, while many lexical forms in the natural environment do not have easily identified visual referents. The experiments in this article show that even lexical forms without referents can facilitate use of phonemic contrasts. Additionally, the results indicate that when lexical forms provide infants with enough variability (for example, a consonant followed by multiple different vowels), infants are able to generalize to novel contexts.

Keywords: words, phonetic units, statistical learning, lexical neighborhoods.

Because of the importance of words to early communication, it is not surprising that milestones such as the emergence of the first word attract a great deal of attention. But in fact, research indicates that the ability to learn words develops gradually across the first years of life, even during periods of time not punctuated by easily observed behavioral milestones. The ability to learn associations between words and visual referents is necessary for word learning and is in place by the time infants are 6 months old (e.g., Bergelson & Swingley, 2010; Tincoff & Jusczyk, 1999). But even at 12 months, around the time when infants typically produce their first word, infants' early learning of label–object relations is immature in many ways compared with the word-learning abilities of older adults and children. Younger infants require more pairings of the word and the referent to learn an association than do older children (e.g., Gershkoff-Stowe & Hahn, 2007; Halberda & Goldman, 2011). Before their first birthday, infants have difficulty learning novel word–object pairings in laboratory settings with impoverished social cues (Werker, Cohen, Lloyd, Stager, & Casasola, 1998). Perhaps most striking, young infants have difficulty using phonemic distinctions when learning labels for novel referents (e.g., Stager & Werker, 1997). For example, 14-month-olds who learn that a novel object is called a */da/* also accept a variety of minimal pair words that differ by only a single phoneme from */da/* as labels for the object (e.g., Pater, Stager, & Werker, 2004; Thiessen & Yee, 2010).

Infants' failure to respond to certain phonemic distinctions is not due to an inability to perceive or encode those distinctions. When the word-learning task is made easier (for example, through provision of more social support), infants are able to use the phonemic differences that they fail to use in habituation tasks (e.g., Fennell & Waxman, 2010). When minimal pair words (such as /da/ and */ta/*) are presented in the absence of a visual referent, 14-month-olds are able to distinguish between them (e.g., Stager & Werker, 1997; Thiessen, 2007). Moreover, when infants learn the label for two novel objects with minimal pairs and are tested with both objects presented simultaneously, they look longer at the correct object. This indicates that they encode the phonemic information well enough to detect which label goes with which object (e.g., Yoshida, Fennell, Swingley, & Werker, 2009). Rather than a perceptual or encoding difficulty, it seems that infants' inability to respond differentially to phonemic contrasts in many tasks arises from a difficulty in *making use* of phonemic distinctions (e.g., Pater et al., 2004; Shvachkin, 1973). While infants perceive and encode the phonemic distinctions that are relevant to their language, they fail to treat these phonemic distinctions as signifying the distinction between tokens of distinct lexical categories (Swingley & Aslin, 2007). The goal in this series of experiments was to investigate how experience with lexical forms affects infants' use of phonemic distinctions. That is, how does the distribution of different phonemes (such as */d/* and */t/*) across lexical forms help to make phonemic distinctions easier to use?

By the time infants are 18 months old, their difficulty in making use of phonemic distinctions is substantially alleviated, at least for the word-initial stop consonants that are typically used in laboratory tasks (e.g., Thiessen, 2007; Thiessen & Yee, 2010). Whereas young infants accept multiple minimal pair words as labels for the same object in habituation tasks, 18-month-olds do not. This developmental change may be linked to vocabulary size; children

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with larger vocabularies are less likely to treat minimal pairs as interchangeable (Werker, Fennell, Corcoran, & Stager, 2002). One potential explanation for this correlation is that experience with word forms themselves plays a causal role in the development of the ability to use phonemic contrasts. Experience with word forms may enable children to use phonemic contrasts more easily, such that infants with larger vocabularies—and, thus, more experience—are more likely to make use of phonemic contrasts.

Indeed, several different theoretical perspectives converge on the importance of vocabulary in the development of phonemic contrasts. One tradition suggests that infants and young children must discover abstract phonemic representations from exposure to the native language. For example, Walley (1993) has proposed that learning minimal pairs (such as *big* and *pig*) forces infants to represent lexical forms more precisely and from this discover that phonemes such as */b/* and */p/* are informative. Similarly, Beckman and Edwards (2000) have proposed that lexical experience (though not necessarily minimal pairs) is a driving force in children's grammatical generalizations at several linguistic levels of representation, including the phonemic level. On both of these accounts, lexical experience focuses infants on abstract, generalizable phonemic representations consistent with linguistic theory (e.g., Chomsky & Halle, 1968). A different viewpoint has emerged more recently that suggests that infants are not—at least initially—discovering abstract linguistic representations but instead are learning about the sound patterns of linguistic input at a perceptual level (e.g., Lotto & Holt, 2003; Thiessen & Yee, 2010). From this perspective, lexical forms are informative to the extent that they help infants resolve the ambiguity inherent in perceptual information (e.g., Swingley, 2009). While these theories differ in the precise role of lexical information, and in the kinds of representations that result from lexical experience (an issue that will be covered in the General Discussion), both concur that experience with phonemes embedded in lexical contexts plays in important role in phonemic development.

To examine the hypothesis that experience with lexical forms plays an important role in children's developing ability to use phonemic information, Thiessen (2007) conducted a laboratory training procedure intended to facilitate use of phonemic contrasts. In that procedure, infants were exposed to phonemic contrasts in distinct contexts such as */d/* and */t/* in */dabo/* and */tagu/* (distinct contexts were contrasted to identical contexts, such as */dagu/* and */tagu/*). The results demonstrated that exposure to phonemes in these distinct contexts facilitated children's use of the phonemic contrast when they were learning novel labels in a word–object association task (for a replication, see Thiessen & Yee, 2010). The facilitation of phonemic contrasts experienced in distinct lexical contexts may be related to the process of *acquired distinctiveness*, in which two similar stimuli become more differentiable as they are paired with distinctive contexts (e.g., Hall, 1991). That is, if an organism has difficulty differentiating between two similar stimuli, A and B (for example, two similar sounds), they can be repeatedly paired with two easily differentiable outcomes, X and Y (X might be punishment, and Y a reward), such that the organism consistently experiences AX and BY pairings. Over time, these pairings reinforce the original (subtle) distinction between X and Y and make it easier to detect.

The hypothesis that acquired distinctiveness plays a central role in the development of infants' ability to use phonemic contrasts is consistent with a causal interpretation of the link between vocabulary and performance in word–object association tasks. This interpretation suggests that a larger vocabulary provides infants with more evidence about the distribution of phonemes in their language, making it easier for infants subsequently to use phonemic contrasts. This is particularly compelling in light of the fact that children are likely to encounter evidence of phonemes in distinct lexical contexts as they develop a lexicon. Compared with the adult lexicon, children's lexicons are less dense and contain fewer minimal pairs. For example, Swingley and Aslin (2007) found that over two thirds of the words in the vocabularies of 18-month-old Dutch-learning infants had no neighbors that differed by only a single phoneme. Similarly, there are no single-feature minimal pair words in the first 50 words English-learning children are most likely to comprehend (Caselli et al., 1995). This is not to say that children know no similar-sounding words. Many English-speaking children are familiar with *ball* and *doll*, or *hi* and *bye*. Rather, these results indicate that children's lexicons are less dense than those of adults. Instead, the words that children acquire between their first and the second birthdays typically provide evidence of phonemes occurring in distinct contexts, as with */d/* and */t/* in *doggy* and *teddy*. This is exactly the kind of experience that should be necessary from an acquired distinctiveness perspective (e.g., Thiessen, 2007; Thiessen & Yee, 2010). The fact that phonemes consistently occur in easily differentiable lexical contexts in the lexicon should serve to reinforce the distinctions between phonemes and make them easier to distinguish.

Although the acquired distinctiveness account presents an explanation for the correlation between vocabulary size and use of phonemes in word–object association tasks, it raises a new set of questions that must be answered before the account is fully specified. Because the acquired distinctiveness account is a learning account, the most central of these questions relate to the process of learning from the input. These experiments are intended to begin to answer two of these questions about the relation between the input and infants' learning. The first question is what portion of the linguistic input available in the environment affects learning. Most research that indicates that linguistic experience affects children's use of phonemic contrasts has focused on the lexicon: word forms with some associated semantic content (e.g., Thiessen, 2007; Werker et al., 2002). However, it may well be the case that simple exposure to word forms – even in the absence of any semantic content – influences performance as well (e.g., Graf Estes, Evans, Alibali, & Saffran, 2007). If so, then a much larger proportion of the input will potentially influence children's performance, not just the words for which children know meanings but potentially every word form that they hear.

The second question is how children generalize their prior experience to novel exemplars of phonemic contrasts. The same phoneme is produced quite differently as a function of speaker, rate, and coarticulatory context. Children's representations of speech store at least some of this contextual and indexical variation (e.g., Houston & Jusczyk, 2003; McMurray & Aslin, 2005). This is consistent with accounts in which representations are not composed solely of abstract, phonologically pure components such as features or phonemes but instead represent speech in a manner that encodes more perceptual detail (e.g., Goldinger, 1998; Werker & Curtin, 2005). However, given the variance in perceptual characteristics in different articulations of the same phoneme, these

perceptual accounts must explain how learners generalize from one instance of a phoneme to novel instances. This does indeed appear to be a challenge for young learners. After training that facilitates the use of phonemic contrasts in one context (e.g., */b/* and */d/* in word-initial position), children fail to generalize their experience to novel contexts, such as contexts where the consonant is followed by a novel vowel or occurs in a different position within a word (Thiessen & Yee, 2010).

I propose that the answers to these two questions are related. If children are able to learn about phonemic contrasts from word forms absent semantic content and not just words for which they know meanings, then they have a much wider range of input that can provide evidence about phonemic contrasts in the language. Indeed, prior research provides reason to believe that infants do store and learn from lexical forms, even when those forms lack semantic information. For example, infants discover phonological regularities simply from overheard word forms with no semantic content (e.g., Chambers, Onishi, & Fisher, 2003; Thiessen & Saffran, 2007). Similarly, exposure to overheard words enhances infants' sensitivity to mispronunciation of the sounds in those words (Swingley, 2007). Additionally, semantically free lexical forms appear to be stored as candidate lexical items. After segmenting words from fluent speech, young children are better able to learn that those words are labels for novel objects than they are to learn entirely novel labels (Graf Estes et al., 2007). These results indicate that infants' memory for lexical forms may encompass a much wider variety of items than simply those words for which they know a meaning.

The possibility that infants and young children may store a wider variety of lexical forms has important implications for the development of phonemic contrasts. Generalization is facilitated when learners experience the same contrast in a wide variety of contexts (e.g., Lively, Logan, & Pisoni, 1993; Singh, 2008). In drawing evidence about phonemic contrast from word forms rather than simply from known words, children are potentially exposed to the same contrast in a much wider range of contexts. The additional contextual variability available from lexical forms without meaning should facilitate generalization. The two experiments described in this article test these hypotheses. Experiment 1 was designed to explore the possibility that children can learn from word forms without semantic content by exposing children to words without paired referents. Experiment 2 was designed to assess whether experiencing phonemes in a variety of contexts facilitates the use of a phonemic contrast in a novel context.

Experiment 1

Fifteen-month-olds fail to respond to differences in minimal pair labels in a word–object association task (e.g., Pater et al., 2004; Shvachkin, 1973). Thiessen (2007) found that exposing children to words in which phonemes occurred in clearly distinct lexical contexts—as */d/* and */t/* in */dabo/* and */tagu/*—facilitates their use of the distinction between minimal pairs. In that experiment, though, */dabo/* and */tagu/* were paired with visual referents so that children had the opportunity to learn that those words referred to novel objects. Thus, the presence of the two distinct objects to which */dabo/* and */tagu/* refer may have been responsible for some, if not all, of the benefit provided by the training. Yeung and Werker (2009) have demonstrated that experiencing distinct objects paired with different phonemes (such as */d/* and */t/*) facilitates infants' use of phonemic contrasts. Therefore, it is possible that the word forms provide little or no benefit, independent of the objects to which they refer.

To determine whether word forms alone are capable of facilitating children's use of a phonemic contrast, researchers presented 15-month-olds in this experiment with */dabo/* and */tagu/* without visual referents. If the word forms alone facilitate children's use of the distinction between */d/* and */t/*, children should benefit from this training as they do when */dabo/* and */tagu/* are paired with visual referents (e.g., Thiessen, 2007; Thiessen & Yee, 2010). This is because exposure to */dabo/* and */tagu/* provides evidence that the phonemes occur in distinct contexts, which should help infants differentiate them (e.g., Hall, 1991). However, if the presence of distinct objects is necessary for infants to benefit from training, simply hearing the word forms */dabo/* and */tagu/* would not facilitate infants' performance when they are asked to differentiate between minimal pairs differing only on the */d/–/t/* contrast.

To ensure that any facilitation found was due to exposure to */d/* and */t/* in distinct contexts and not simply to increased exposure to the phonemes, a second group of infants heard */d/* and */t/* in an identical context. Rather than listening to */dabo/* and */tagu/*, this second group of participants listened to */dagu/* and */tagu/*. In */dagu/* and */tagu/*, */d/* and */t/* occur in identical contexts that should not give rise to acquired distinctiveness. Indeed, when two differentiable stimuli are paired with the same outcome or context, they become harder to differentiate (e.g., Honey & Hall, 1989). Prior research (in which novel words with referents were used) has demonstrated that while exposure to */dabo/* and */tagu/* facilitates use of the */d/–/t/* contrast, exposure to */dagu/* and */tagu/* does not (Thiessen, 2007; Thiessen & Yee, 2010). The same difference between identical (*/dagu/* and */tagu/*) and distinct (*/dabo/* and */tagu/*) contexts should occur in this experiment, which is a conceptual replication of the Thiessen's (2007) experiment without object referents for the words (*/dagu/*, */tagu/*, and */dabo/*) that serve to provide contexts for the */d/–/t/* contrast.

Method

Participants. Thirty-two infants (16 girls, 16 boys) between the ages of 15 and 16 months ($M = 15.6$ months) participated in this experiment. Half of these infants were randomly assigned to the identical contexts condition, and the other half were assigned to the distinct contexts condition. Eight additional infants were tested but excluded from the final analysis because of fussiness (six), failure to attend to the stimuli (one), and experimenter error (one). All infants were recruited from the Pittsburgh region via mailings and recruiting calls to their parents. While data on ethnicity and socioeconomic status were not collected for individual infants, the population of infants from which the participants were drawn is primarily White and middle class. According to parental report, all of the infant participants heard English at least 75% of the time in the home.

Procedure. This experiment had a three-stage procedure: familiarization, habituation, and testing. In all three stages, the child was seated 150 cm away from a 32-in. (81.28-cm) video monitor on a caregiver's lap in a sound-attenuated room. An experimenter seated outside the room observed the infant and recorded the duration of his or her gaze at the central monitor using

Habit X software (Cohen, Atkinson, & Chaput, 2004). To eliminate bias, parents were asked to wear headphones, and the experimenter was blind to the nature of the stimulus being presented. Two speakers situated next to the central monitor were used to present all audio stimuli.

During the first stage of the experiment, the familiarization stage, only audio stimuli were presented. In this stage, infants were familiarized with two words providing evidence of */d/* and */t/* in lexical contexts (distinct contexts condition: */dabo/* and */tagu/*; identical contexts condition: */dagu/* and */tagu/*). The words during this stage were not paired with referents, as the central monitor remained blank during this time. This first stage of the experiment lasted approximately 30 s. The stimuli during this stage were not under the infant's control and were presented regardless of the infant's behavior.

When the first stage of the experiment was finished, the second stage of the experiment began. This stage used a habituation procedure identical to that used in Thiessen (2007) in which the infant controlled the duration of the stimulus presentation. The habituation phase began with a colorful video of Winnie the Pooh appearing on the central monitor that was presented to attract the infant's attention. Once the experimenter determined the child's attention was fixated on the monitor, stimulus presentation was initiated. An object then appeared on the screen, and the speakers adjacent to the monitor began to repeat the label associated with that object. The stimulus presentation continued until the child looked away for more than 1.5 s or until the child had gazed at the monitor for 20 s (the maximum time allowed per trial). The video of Winnie the Pooh appeared at the end of each trial to recapture the child's attention.

During the habituation trials, a single novel object appeared on the monitor and was paired with the label */da/*. The object oscillated from left to right while the label was repeated. The object and the label were presented until the child looked away from the monitor for 1.5 s, at which point the attention-getting stimulus reappeared. Looking times to each trial were calculated in real time, and the habituation trials continued until the infant met the habituation criterion: average looking time for three consecutive trials that fell below 50% of the infant's looking time to the first three habituation trials.

Once the infant met the habituation criterion, the testing stage began. There were two kinds of test trials: *Same* and *Switch* trials. On both kinds of trials, the object from the habituation phase was presented on the monitor, moving in the same manner as it had during habituation. On Same trials, the object was paired with the same label that was associated with it during the habituation phase (*/da/*). In the Switch trials, the object was paired with a minimal pair of the label infants had heard in the habituation phase (*/ta/*). Same and Switch trials alternated, and the nature of the initial test trial was counterbalanced across participants. As in the habituation trials, the object stayed on the screen, and the label continued to repeat for as long as the participant continued to look at the monitor. There were six total test trials, three Same trials and three Switch trials.

Stimuli. The word forms used during all three stages of the experiment were synthesized using the SoftVoice text-to-speech synthesizer (SoftVoice, Inc., Los Angeles, CA), and were identical to those used in Thiessen (2007). All sounds were played at a level approximating conversational speech, around 65 dB. During the familiarization phase, infants were exposed to words in the absence of visual referents; the monitor screen was blank during this portion of the experiment. Each pair of words (*/dabo/* and */tagu/* for infants in the distinct-contexts condition; */dagu/* and */tagu/* for infants in the identical-contexts condition) was repeated six times. Therefore, during the familiarization phase, each infant heard 12 word tokens, with a pause of 1.4 s between each word. After the initial word (*/dabo/* for all infants), members of the pair were presented in alternating order, until all 12 tokens had been presented.

During the habituation phase, infants saw a novel object on the monitor, paired with the label *da*. The object was one of the ones used in Stager and Werker's (1997) experiments, a blue semicircle with red fingerlike protrusions, animated to move against a black background. The label associated with the object repeated for as long as the child looked at the monitor, with pauses of 1.4 s between each repetition. During the test phase, infants saw the same object as during the habituation phase. On Same trials, this object was paired with the label */da/*. On Switch trials, it was paired with the label */ta/*, which was also synthesized in SoftVoice with the same volume, pitch, and duration parameters.

Results and Discussion

On average, infants habituated in 9.5 trials. There was no significant difference in the rate of habituation as a function of whether infants had been familiarized—before the habituation phase—with */dabo/* and */tagu/* ($M = 9.4$, $SD = 4.0$) or */dagu/* and */tagu/* ($M = 9.5$, $SD = 4.2$), $t(30) < 1$, *ns*. Although, familiarization did affect infants' performance during the test phase. As illustrated in Figure 1, infants familiarized with */dagu/* and */tagu/* responded equivalently to Switch ($M = 3.6$, $SD = 1.9$) and to Same ($M = 3.8$, $SD = 1.8$) trials, $t(15) < 1$, *ns*; 95% confidence interval (CI) of difference [1.1, −1.4 s]. This is expected for participants in this age group because they have difficulty responding differentially to minimal pairs such as */da/* and */ta/* (e.g., Pater et al., 2004; Stager & Werker, 1997; Thiessen & Yee, 2010). Familiarization with the phonemes */d/* and */t/* in the same context

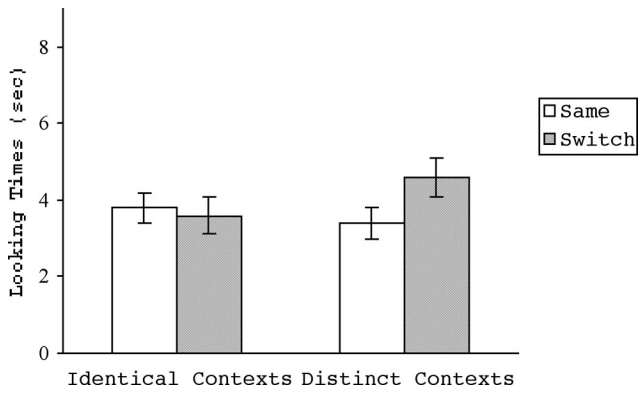

Figure 1. Infants' looking times to Same (*/da/*) and Switch (*/ta/*) trials after habituation. Infants in the identical contexts condition were familiarized with */dagu/* and */tagu/*, while infants in the distinct context condition were familiarized with */dabo/* and */tagu/*. Error bars indicate ± standard error.

does not yield acquired distinctiveness and thus does not facilitate use of the distinction (e.g., Thiessen, 2007).

By contrast, children familiarized with */dabo/* and */tagu/* looked significantly longer to Switch trials ($M = 4.6$, $SD = 1.8$) than to Same trials ($M = 3.4$, $SD = 1.5$), $t(15) = 2.97$, $p < .05$, $d = 0.7$, 95% CI of difference [0.9, 3.2 s]. That exposure to */d/* and */t/* in *distinct* contexts facilitates use of the distinction replicates several prior results (e.g., Thiessen, 2007; Thiessen & Yee, 2010; Yeung & Werker, 2009). One striking fact about these results is how little input is required to facilitate infants' use of phonemic contrasts. The familiarization phase consisted of only six tokens of each member of the word pair (12 tokens in total) and yet was enough to alter performance during the test trials. This is consistent with work by Swingley (2007) that indicated that exposure to a novel word a mere 14 times facilitated 18-month-olds' detection of mispronunciations of the word.

More important, though, these results demonstrate that exposure to lexical forms without accompanying referents is sufficient to facilitate use of phonemic contrasts. Indeed, the effect size of infants' dishabituation in Thiessen (2007), where infants were exposed to */dabo/* and */tagu/* with object referents, was 0.76, which is very similar to the effect size (0.7) found in the current experiment where */dabo/* and */tagu/* were presented without referents. This should not be taken to mean that objects play no role in helping to disambiguate phonemic contrasts. Indeed, pairing phonemes with distinct objects heightens the distinctiveness of the phonemes (Yeung & Werker, 2009). Instead, these results indicate that word forms contribute independently to children's developing ability to make use of phonemic contrasts. That is, word forms with no associated meaning may influence children's use of phonemic contrasts. Given the number of tokens required to affect performance, children may not even need extensive experience with a particular word form before it begins to influence their use of a phoneme. However, caution is warranted when generalizing from a laboratory setting with concentrated exposure to only a few words to the complexity of natural language. The issue of how word forms, and known words, might work to affect use of phonemes during language development will be covered in more detail in the General Discussion.

Experiment 2

Experiment 1 indicated that word forms, without any associated visual referents, can influence use of phonemic contrasts. This lends credence to accounts of the development of phonemic contrasts that emphasize the role of experience with words (e.g., Thiessen, 2007). Although there is no easy way to estimate the number of word forms with which children are familiar (for discussion, see Swingley, 2005b), infants are necessarily exposed to more word forms than to words whose meanings they know. If word forms (even with no associated visual referents) influence phonemic development, the quantity of linguistic input that can affect infants' use of phonemes is much larger than previously thought. This suggests that the relatively rapid development of the use of phonemic contrasts is plausible due to the amount of input available to shape infants' use of the phonemic inventory of their native language. Prior research has suggested that infants' development of the use of phonemic contrasts is indeed relatively rapid, with improvements in the ability to use phonemes in novel label–object association tasks occurring in as little as 3–4 months (e.g., Thiessen, 2007; Werker et al., 2002).

Experiment 1, then, supports the hypothesis that development (even relatively rapid development) in children's use of phonemic changes is due in part to experience with the distribution of phonemes in the words infants hear. However, there is a potential difficulty that an experience-driven account must overcome. This is the fact that prior experiments demonstrating that experience can influence children's use of phonemic contrasts have also shown that children are poor at generalizing from their experience. When children experience a phonemic contrast in a particular setting (e.g., a syllabic position or preceding a particular vowel), they learn about the phoneme in that setting but fail to generalize their experience to a novel setting (e.g., Thiessen & Yee, 2010). For example, children who are exposed to */dabo/* and */tagu/* are facilitated in their use of the distinction between */da/* and */ta/* (as demonstrated in Experiment 1) but treat *dI* and *tI* interchangeably. Given how rapidly infants develop the ability to use phonemic contrasts (over the course of only a few months), this lack of generalization is potentially problematic for an experience-driven account. There are a number of different settings in which any phonemic contrast can occur (e.g., followed by any of several vowels, in a cluster or in isolation, in different syllabic positions). If children are only able to learn about one setting at a time, an experience-driven account of rapid developmental change is implausible.

However, prior experiments assessing children's ability to generalize from distributional information presented participants with a phoneme in only one setting (Thiessen & Yee, 2010). This may underestimate infants' ability to generalize, as increased variability in the input can promote generalization (e.g., Gómez, 2002). Using the Switch task, Rost and McMurray (2009) have shown that exposure to a single word form produced by multiple speakers facilitates use of the phonemic contrast, presumably by helping infants to focus on the critical dimensions of contrast between phonemes. While exposure to a contrast in one setting may not be enough to support generalization to novel contexts (at least early in learning), exposure to a context in multiple settings may enable infants to generalize by helping them to focus on those characteristics of the phoneme that are constant across setting. Hearing a phoneme in multiple contexts may lead to comparison processes across memory traces that emphasize the relatively invariant phonemic information, while deemphasizing the less consistent information about the contexts in which phonemes occurred (e.g., Hintzman, 1986; Singh, 2008). This process is not limited to memory for acoustic information and is likely related to the prototype enhancement effect whereby exposure to multiple exemplars allows learners to generalize to a novel item near the center of the exemplars they have observed (Posner & Keele, 1968).

To test the hypothesis that exposure to phonemes in multiple settings would enable infants to generalize to novel settings, experimenters during the familiarization phase of Experiment 2 presented infants with evidence that phonemes occur in distinct lexical contexts (such as */dabo/* and */tagu/*). However, rather than only a single word pair, three word pairs were used that allowed participants to experience the */d/–/t/* contrast in different syllabic settings. If infants are unable to generalize from their prior experience with phonemic contrasts, this increase in syllabic variability

should have no effect, and infants should still fail to use the */d/–/t/* contrast in a novel syllabic setting (e.g., Thiessen & Yee, 2010). In contrast, if infants are able to generalize, then those exposed to multiple syllabic settings should be more successful at using the phonemic contrast in a novel setting.

Method

Participants. Thirty-two infants (16 girls, 16 boys) between the ages of 15 and 16 months ($M = 15.5$ months) participated in this experiment. In order to obtain data from 32 infants, it was necessary to test 36. The other four were excluded for the following reasons: fussiness (three) and experimenter error (one). All infants were recruited from the Pittsburgh region via mailings and recruiting calls to their parents. According to parental report, all of the infant participants heard English at least 75% of the time in the home.

Procedure. The procedure used in Experiment 2 (familiarization, habituation, test) was identical to that used in Experiment 1. There were two groups of participants. Half of the participants were randomly assigned to the *Consistent Setting* condition and heard */dabo/* and */tagu/* during the familiarization phase. The other half were assigned to the *Variable Setting* condition and heard /*dusi*/, /*tukʊl*/, /*difo*/, and /*tila*/, in addition to */dabo/* and */tagu/*. After familiarization, all infants were habituated to a pairing between a novel object and an associated label (/*dIv*/).

Stimuli. For infants in the Consistent-Setting condition, the stimuli used during the familiarization phase were identical to those used in Experiment 1. The additional word forms heard by infants in the Variable-Setting condition (/*dusi*/, /*tukʊl*/, /*difo*/, and /*tila*/) were synthesized using the same parameters as were used in the creation of the stimuli for Experiment 1. Infants in both conditions heard 12 words during the familiarization phase, for an identical duration across conditions. Thus, infants in the Consistent-Setting condition heard six tokens of two words (*/dabo/* and */tagu/*), while infants in the Variable-Setting condition heard two tokens of each of the six words.

After familiarization, infants were habituated to an animated object (identical to that used in Experiment 1) paired with the label /*dIv*/. This label was synthesized with the same parameters that were used in the creation of the familiarization stimuli. Notice that in this label the phoneme */d/* was followed by a novel vowel context relative to the familiarization stimuli. Furthermore, this label is a consonant–vowel–consonant syllable, unlike the consonant–vowel syllables from the familiarization phase. Therefore, any learning about the */d/–/t/* contrast from the familiarization phase must be generalized to a novel context, which is difficult for 15-month-old infants in this procedure (Thiessen & Yee, 2010).

After habituation, infants were presented with Same and Switch trials. On both trials, the animated object was presented on the central monitor. On Same trials, it was paired with the same label (/*dIv*/) as in the habituation phase. On Switch trials, it was paired with a minimal pair (/*tIv*/). Both of the labels used in the habituation phase were synthesized with the same parameters as in Experiment 1.

Results and Discussion

On average, infants habituated in 8.4 trials. There was no significant difference in rate of habituation whether infants were in the Consistent-Setting ($M = 8.5$, $SD = 3.8$) or the Variable-Setting ($M = 8.3$, $SD = 4.1$) conditions, $t(30) < 1$, *ns.* As illustrated in Figure 2, infants in the Consistent-Setting condition failed to differentiate between Switch trials ($M = 5.1$, $SD = 2.4$) and Same trials ($M = 4.9$, $SD = 1.5$), $t(15) < 1$, *ns*; 95% CI of difference [1.4, −1.1 s]. These results replicate the lack of generalization found by Thiessen and Yee (2010). Exposure to phonemes in distinct contexts (such as */d/* and */t/* in */dabo/* and */tagu/*) facilitates use of the phonemic contrast but only in the same syllabic setting (i.e., */da/* and *ta*). Infants fail to generalize their use of the contrast to a novel syllabic setting (i.e., /*dIv*/ and /*tIv*/).

In contrast to infants in the Consistent-Setting condition, infants in the Variable-Setting condition responded differentially to the test trials. These infants listened significantly longer to Switch trials ($M = 5.6$, $SD = 2.3$) than to Same trials ($M = 3.6$, $SD = 1.5$), $t(15) = 3.9$, $p < .05$, $d = 1.1$; 95% CI of difference [0.9, 3.1 s]. Unlike infants in the Consistent-Setting condition, infants in the Variable-Setting condition were able to generalize their knowledge of the */d/–/t/* contrast to a novel syllabic setting. After exposure to an object labeled /*dIv*/, they dishabituated to seeing the same object labeled as /*tIv*/. Given that the habituation and test trials were identical for infants in the Consistent- and Variable-Setting familiarization conditions, the difference in performance across the conditions can only be attributed to the difference in familiarization.[1]

The contrast between these two conditions indicates that experience with phonemic contrasts is initially limited in its ability to facilitate use of those contrasts in object–label association tasks. After experiencing a contrast in a single setting (the Consistent-Setting condition), infants are initially restricted to using the contrast in that setting, replicating the results of Thiessen and Yee (2010). But infants' performance is quite different when they are exposed to a contrast in several different syllabic settings. After exposure to evidence that the phonemes */d/* and */t/* occur in different contexts, presented in multiple different syllabic settings, infants are able to generalize their use of the contrast to a novel setting. This is the first evidence that such experience generalizes to novel settings. That infants are able to generalize in this context makes developmental accounts of phonemic usage that emphasize learning from experience more plausible.

General Discussion

The results of these two experiments present two complementary findings relating to infants' ability to learn about the use of

[1] An alternative possibility, suggested by an anonymous reviewer, is that infants were more successful in the Variable-Setting condition because they were exposed to the */d/–/t/* contrast in /*difo*/ and /*tila*/, a vocalic setting that is similar to the test items (because */i/* is similar to the vowel */I/* in /*dIv*/ and /*tIv*/). To assess this possibility, experimenters tested an additional group of 16 infants in a new version of the Consistent-Setting condition, in which the infants were familiarized with repetition of /*difo*/ and /*tila*/ (rather than */dabo/* and */tagu/*). Like infants in the original Consistent-Setting condition, these infants responded equivalently to Switch ($M = 4.9$, $SD = 2.1$) and Same ($M = 4.9$, $SD = 1.7$) trials after habituation, $t(15) < 1$, *ns*; 95% C.I. of difference: [1.3, −1.1 s]. These results suggest that infants fail to generalize between even relatively similar vocalic settings such as /*di*/ and /*dI*/, if there is no variability in the vocalic setting during familiarization.

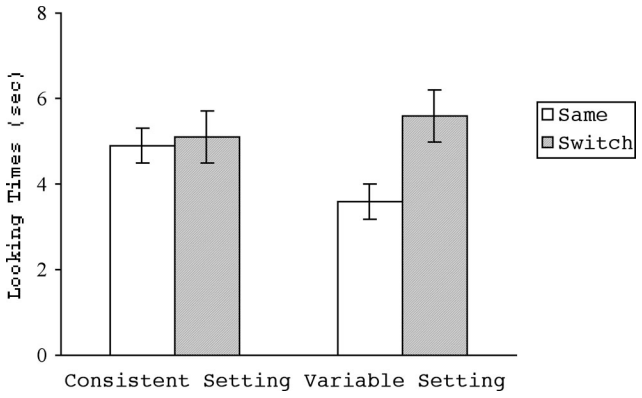

Figure 2. Infants' looking times to Same (*/dIv/*) and Switch (*/tIv/*) trials after habituation. Error bars indicate ± standard error.

phonemic contrasts in label–object association tasks. Prior research has demonstrated that exposure to similar phonemes (such as */d/* and */t/*) in distinct lexical contexts facilitates use of the phonemic contrast (Thiessen, 2007; Thiessen & Yee, 2010). The first novel finding of the current experiments is that lexical contexts alone, even in the absence of objects, yield this effect. This should not be taken to mean that objects play no role in disambiguating phonemic contrasts. As shown by Yeung and Werker (2009) pairing similar phonemes with distinct objects can facilitate use of a phonemic contrast. Instead, these results indicate that word forms alone, even word forms for which infants do not have an associated meaning, can influence use of phonemic contrasts.

The second novel finding of the current experiments is that infants are able to generalize their experience with phonemic contrasts to novel syllables, yet to do so they must experience the contrast in a variety of settings. If infants are exposed to those phonemes that occur in only a single vocalic context, their learning is limited to that context. In contrast, when infants are exposed to evidence that is distributed across three vocalic contexts, they are able to generalize and use the phonemic contrast even when it is followed by a novel vowel. Given the variability of acoustic realizations of the same phoneme (e.g., Cole & Scott, 1974; Dinnsen, O'Connor, & Gierut, 2001), the ability to generalize from prior experience is necessary if learners are to benefit from previous experience. The fact that infants are able to do so makes an experience-driven account of the development of phonemic contrasts more plausible. Moreover, the possibility that infants can benefit from word forms absent of meaning—in addition to words with a known meaning—provides infants with a much larger pool of experience from which to generalize. Taken together, then, Experiments 1 and 2 fit within the framework of an experience-driven perspective on the development of phonemic contrasts for word learning. In the remainder of this General Discussion, I will present an outline of such a developmental perspective and illustrate in more detail how the current results fit into that perspective.

By 11–12 months, and even younger in cases of redundant input, infants are able to associate labels with visually presented objects (e.g., Gogate & Bahrick, 1998, 2001; Tincoff & Jusczyk, 1999; Werker et al., 1998). These early associations are not "words" in the traditional linguistic sense—for example, they lack syntactic function—but are undoubtedly important in early communication and lay a foundation for subsequent linguistic competence (e.g., Bates, Dale, & Thal, 1995; Fenson et al. 1994). Although these early label–object associations are immature in many respects, a variety of converging evidence indicates that many of the acoustic details of the labels are represented accurately in infants' memory (e.g., Fennell & Werker, 2003; Swingley, 2005a; Vihman, Nakai, DePaolis, & Hallé, 2004; though see Hallé & Boysson-Bardies, 1996). For example, infants are sensitive to mispronunciations of known words (such as when *baby* is pronounced as *vaby*), and they orient to the intended referent more slowly when the word is mispronounced (Swingley & Aslin, 2000, 2002). Further, this mispronunciation effect can be obtained not only for well-known words but also for novel label–object associations learned in a laboratory setting (Yoshida et al., 2009). Indeed, infants' representations of word forms store not only phonological detail but also indexical detail such as speaker identity (e.g., Houston & Jusczyk, 2003). This kind of research suggests that infants' representations of speech contain a great deal of phonetic detail, in contrast to theories claiming that infants' representations are underspecified (e.g., Shvachkin, 1973).

The possibility that early lexical representations are well specified, though, presents a question relevant to the current experiments: why do infants fail to respond to the difference in minimal pairs in word–object association tasks? Thiessen (2007) suggested that it is because infants are not yet familiar with the function of phonemic contrasts. This is consistent with Werker and Curtin's (2005) proposal that infants must discover which of the acoustic properties in the input are relevant for meaning (i.e., are phonemic) due to the wealth of acoustic details contained in early word-form representations. There are a number of domains in which infants initially fail to take advantage of acoustic distinctions; this period lasts until they have some amount of subsequent experience that allows them to make use of the distinction. For example, infants are able to perceive allophonic distinctions and lexical stress for many months before they begin to use these perceptual features as cues to word segmentation (e.g., Hohne & Jusczyk, 1994; Jusczyk, Hohne, & Bauman, 1999; Jusczyk & Thompson, 1978; Thiessen & Saffran, 2003). Similarly, it may be that 14- to 15-month-olds perceive and represent the acoustic differences between minimal pair words like */da/* and */ta/*, but they do not yet have the relevant experience that prompts older children to treat minimal pairs as distinct in labeling tasks.

The acquired distinctiveness hypothesis invokes a straightforward mechanism via which experience can influence use of a phonemic contrast. According to this hypothesis, the critical experience is exposure to phonemes in distinct contexts (e.g., */d/* and */t/* in */dabo/* and */tagu/*, or *diaper* and *teddy*). From this perspective, learning minimal pairs is unlikely to play an important role in phonemic development, consistent with prior arguments that they do not play a key role in early learning (Maye & Gerken, 2000; Maye, Werker, & Gerken, 2002). Instead, through acquired distinctiveness, sounds that are initially very similar become more distinct as they occur in distinct contexts (e.g., Thiessen, 2007; Yeung & Werker, 2009). In laboratory settings, acquired distinctiveness renders minimal pairs distinct enough that infants will respond to them differentially in habituation experiments (Thiessen, 2007; Thiessen & Yee, 2010). Note that even without training that gives rise to acquired distinctiveness, infants are able to hear and represent the difference between minimal pairs (e.g., Stager &

Werker, 1997; Yoshida et al., 2009). Acquired distinctiveness serves to make more robust the distinction between phonemes in a minimal pair. A prediction implied by this hypothesis is that infants should require less or no acquired distinctiveness training to use phonemes that are more distinct and should require more training to take advantage of phonemic contrasts that are less perceptually distinct.

From this perspective, the difference between 14-month-olds (who fail to respond differentially to minimal pairs in the Switch task) and 17-month-olds (who succeed in the task) is that older infants have more experience with the phonemes of their native language. In particular, they have more exposure to these phonemes occurring in distinct contexts because they know more words (e.g., Dale & Fenson, 1996). Because infants and young children know very few minimal pair words (Caselli et al., 1995; Charles-Luce & Luce, 1990, 1995; Coady & Aslin, 2003; Swingley & Aslin, 2007), the words that infants and young children know are likely to provide evidence of phonemes occurring in distinct lexical contexts. Thus, as infants become familiar with more words, they receive more evidence that should make phonemes distinct, via the process of acquired distinctiveness. This hypothesis provides an explanation for the results of Werker et al. (2002), indicating that 14-month-olds with larger vocabularies are more likely to succeed in the Switch task. However, it must be noted that while other researchers have reported correlations between vocabulary size and use infants' use of phonemic contrasts (e.g., Mani & Plunkett, 2010; Yoshida et al., 2009), some researchers have failed to find a correlation (e.g., Mani & Plunkett, 2008; Swingley & Aslin, 2000, 2002). A fully specified hypothesis about the relation between lexical experience and use of phonemic contrasts should be able to explain these inconsistent results.

One potential reason for this inconsistency is differences in procedure. For example, Swingley and Aslin (2000, 2002) failed to find correlations between vocabulary and use of phonemic contrasts. But there are several ways in which the task used by Swingley and Aslin differs from the Switch task: infants are tested with familiar words, in a preferential looking task, and are not habituated to the stimuli. These differences result in a task where infants are sensitive to phonemic differences, unlike in the Switch task, indicating that the Switch task is more difficult (i.e., that it requires more robust differentiation between phonemes). Indeed, the fact that infants succeed may explain why Swingley and Aslin (2000, 2002) fail to find a vocabulary correlation. When learning labels for novel objects, there is a correlation between vocabulary size and ability to use phonemic distinctions at 14 months (e.g., Yoshida et al., 2009). For older infants, though, there is no correlation between vocabulary size and use of phonemic contrasts (Werker et al., 2002). From the perspective that experience with phonemes in the lexicon helps to support phonemic distinctions, this lack of correlation can be explained in terms of a threshold. Once infants at a particular age have acquired enough lexical information to support phonemic distinctions in a task (where different tasks require more or less robust differentiation), correlations with vocabulary will fade because all of the infants are above the threshold. That is, correlations should only be found at those ages where some infants succeed in a task, and other infants fail. This age may be different as a function of the contrast in question. It may be the case, for example, that vowel contrasts emerge earlier than consonantal contrasts. This would explain why vocabulary size appears to affect use of vocalic contrasts at 12 months, but not at 14 months (Mani & Plunkett 2008, 2010).

However, the results of Experiment 1 also suggest another potential reason for the disparity between experiments that show correlations between vocabulary and use of phonemic contrasts and those that do not. Vocabulary size may be an inexact measure of infants' lexical experience, because vocabulary size is explicitly a measure of those words for which infants have some associated meaning. But as the results of Experiment 2 indicate, infants benefit from experience with lexical forms that have no meaning and likely store these forms in memory (e.g., Graf Estes et al., 2007; Houston, & Jusczyk, 2003). In many cases, vocabulary size and overall lexical experience are related. Vocabulary size is linked to overall amount of exposure to speech (i.e., lexical forms) in the environment (e.g., Hurtado, Marchman, & Fernald, 2008; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). It is plausible that the lexical forms in the lexicon are, in many cases, a representative sample of the lexical forms present in the linguistic environment.

In some cases, though, the effect of overheard lexical forms may deviate from the effect expected from known words in the lexicon. It may be the case, for example, that the distribution of words in the lexicon is skewed relative to the distribution of lexical forms stored in memory. One reason such a skewing might arise is if there are two lexical forms that are equally frequent in the input (and thus would be equally likely to be stored in memory), but the meaning of one lexical form is more easily learned than the other lexical form, as may be the case with nouns and verbs (Gentner, 1982). If it is the case that the population of overheard lexical forms is systematically different than the population of word forms in the lexicon, then the use of phonemic contrasts may obey the distribution of overall lexical forms, rather than the distribution of known words. Conversely, though, when an infant is tested with a known word, the experience with that particular word may be more important than the distributional information about the phonemes that compose the word and the distribution of those phonemes in other lexical forms. This may explain why infants are more likely to respond differentially to phonemic contrasts when tested with familiar words (e.g., Bailey & Plunkett, 2002; Swingley & Aslin, 2000, 2002).

Beyond facilitating use of phonemic contrasts, these experiments suggest another way in which experience with lexical forms plays an important role in development. Prior research indicates that infants do not automatically generalize their experience with speech sounds at an abstract, phonemic level (e.g., Singh, White, & Morgan, 2008). What an infant knows about */d/* in the context of */da/* does not immediately generalize to */d/* in the context of */dIv/* (Thiessen & Yee, 2010). Similarly, even when infants treat a featural contrast (such as voicing) as informative in one phonemic pair, they may not use it in other phonemic pairs (Thiessen & Yee, 2008). This suggests that infants are not weighting phonemic identity or featural information as heavily as mature language users. Indeed, it may be that infants' early word forms are not composed of the kind of abstract and symbolic phonemic units that are often thought to compose adults' knowledge of word forms (though see Lotto & Holt, 2003). Instead, infants may be learning about more perceptual categories and using lexical information to help to disambiguate those categories (Swingley, 2009). From this perspective, abstract phonemic representations would develop only

over the course of experience, rather than organizing lexical knowledge from the onset of learning. This kind of developmental trajectory would be consistent with research on older children suggesting that phonemic knowledge develops over the course of several years (e.g., Walley, 1993; Walley, Metsala, & Garlock, 2003). Experiment 2 suggests one route through which a more mature representational system might emerge: through exposure to phonemes and features in a wide variety of contexts. In much the same way as exposure to the */d/–/t/* contrast in a variety of settings allowed infants to generalize the contrast to a novel setting, exposure to voicing contrasts in a wide variety of settings may lead infants to be more willing to treat voicing as contrastive in novel settings.

Moreover, knowledge of phonemic and featural contrasts is not only important for word recognition but perhaps even more important for determining when an utterance is a token of a *novel* word. In the current experiments, infants were too willing to treat minimal pairs as labels for the same object. This implies that they should be less able to learn that the minimal pairs such as */da/* and */ta/* actually refer to different objects (that is, that */ta/* is a token from a different category than */da/*). In fact, 18-month-olds do appear to have difficulty with this, as they are inhibited in learning associations between novel objects and lexical forms that are minimal pairs of words they already know (Swingley & Aslin, 2007). This is consistent with the hypothesis that infants have difficulty making functional use of the distinction between phonemes in their native language. It may also explain why minimal pairs are underrepresented in the developing lexicon. One counterintuitive suggestion from this research is that infants may need to learn a variety of words where phonemes occur in distinct contexts (such as */d/* and */t/* in *doggy* and *teddy*) before their phonemic distinctions are robust enough to support more extensive learning of minimal pair words.

Although the current results present more evidence that experience with phonemes in distinct contexts can be informative, they also strike a note of caution. All of the prior analyses of the characteristics of infants' lexicons have focused on words for which children have some associated meaning (often as rated by parents). Yet as Experiment 1 indicates, known words are not the only source via which children acquire information about phonemes. Frequently heard word forms, even with no associated meanings, can also influence children's use of phonemic contrasts. Thus, to completely understand the role that experience with phonemes in different lexical contexts plays in development, it is important to characterize more than just the words for which infants know meaning. It is also important to characterize the word forms they hear, especially those lexical forms that are heard often enough to plausibly be stored in memory even without any associate meaning. Characterizing the input more fully may reveal unexpected insights into the nature of the distribution children experience and will certainly provide a better database for making predictions about how experience with the input influences subsequent learning.

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