INFANCY, *3*(1), 1–30

RESEARCH ARTICLES

Infants' Ability to Learn Phonetically Similar Words: Effects of Age and Vocabulary Size

Janet F. Werker, Christopher T. Fennell,
Kathleen M. Corcoran, and Christine L. Stager
Department of Psychology
University of British Columbia

What do novice word learners know about the sound of words? Word-learning tasks suggest that young infants (14 months old) confuse similar-sounding words, whereas mispronunciation detection tasks suggest that slightly older infants (18–24 months old) correctly distinguish similar words. Here we explore whether the difficulty at 14 months stems from infants' novice status as word learners or whether it is inherent in the task demands of learning new words. Results from 3 experiments support a developmental explanation. In Experiment 1, infants of 20 months learned to pair 2 phonetically similar words to 2 different objects under precisely the same conditions that infants of 14 months (Experiment 2) failed. In Experiment 3, infants of 17 months showed intermediate, but still successful, performance in the task. Vocabulary size predicted word-learning performance, but only in the younger, less experienced word learners. The implications of these results for theories of word learning and lexical representation are discussed.

By their first birthday, infants display a set of perceptual sensitivities that are ideally suited for mapping the stream of speech onto meaningful words. Very young infants discriminate phonetic distinctions used across all the world's languages, but

---

Supplementary materials to this article are available on the World Wide Web at http://www.infancyarchives.com.

Requests for reprints should be sent to Janet F. Werker, 2136 West Mall, Department of Psychology, University of British Columbia, Vancouver, BC, V6T 1Z4, Canada. E-mail: jwerker@cortex.psych.ubc.ca

by 10 to 12 months of age they selectively discriminate only those consonant and vowel distinctions that have phonemic significance (are used to distinguish meaning) in their native language (Best, McRoberts, LaFleur, & Silver-Isenstadt, 1995; Pegg & Werker, 1997; Polka & Werker, 1994; Tsao, Liu, Kuhl, & Tseng, 2000; Werker & Lalonde, 1988; Werker & Tees, 1984). By this age infants are also familiar with a number of other phonological regularities in the native language, including stress patterns (Jusczyk, Cutler, & Redanz, 1993), phonotactic regularities (Friederici & Wessels, 1993; Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993), and their probability of occurrence (for a review, see Jusczyk, 1997). Moreover, they can combine their knowledge of phonetic properties with prosodic information (Morgan & Saffran, 1995) and use this to pull out "words" from the speech stream (Myers et al., 1996; see Jusczyk, 1999, for a full review). The question guiding the current set of studies is this: Do infants use the perceptual knowledge they have acquired across the first year of life in word-learning tasks?

Child phonologists have classically argued that the answer to this question is no. Many maintain that there is a discontinuity between the phonetic representations used in speech discrimination tasks and the phonological representations required for language use (Ferguson & Farwell, 1979; Keating, 1984, 1988; Pierrehumbert, 1990). Almost all work in child phonology suggests that only gradually, as they acquire words, do children come to represent the more detailed information that might distinguish one possible word from another (Brown & Matthews, 1997; Brown, in press; Edwards, 1974; Garnica, 1973; Kay-Raining Bird & Chapman, 1998; Merriman & Schuster, 1991; Pollock, 1987; Shvachkin, 1948/1973). Indeed, during the toddler years, discrimination of minimally different words is only evident for words that the toddler knows well (Barton, 1980), and even then, perceptual confusions do occur (Eilers & Oller, 1976). All of these studies support the notion that, at the earliest stages of learning a new word, children represent the words only globally.

Prior to mapping words onto meaning, attention to phonetic detail is evident, however. In one study, Jusczyk and Aslin (1995) found that after being familiarized to words such as *dog* and *cup*, infants 7 to 8 months of age listen to those words longer than to unfamiliar foils such as *feet* and *bike.* More important, they also listen longer to *dog* and *cup* than to minimally different foils such as *bog* and *tup*, indicating that their representation of familiar word forms does contain fine phonetic detail. In a similar testing procedure, but without familiarization to the words in the laboratory (as was done by Jusczyk & Aslin, 1995), Hallé and de Boysson-Bardies (1994) tested infants 11 and 12 months of age on their preference for words that occur with high frequency in the speech to children in comparison to low-frequency words. The infants chose to listen longer to the more common words. However, when infants of this age were tested with foils that were phonetically similar to commonly occurring words, no preference was found (Hallé & de Boysson-Bardies, 1996). This finding suggests that in infants of 11 to 12 months, the representation of known words picked up from the input does not contain fine phonetic detail, that is, it does not reflect the full range of perceptual sensitivities available to the child at this age.

How can we reconcile the differences between Jusczyk and Aslin's finding of detailed representations being used in word recognition at 7½ months and Hallé and de Boysson-Bardies' (1996) finding that at 11 months of age infants do not utilize such detailed representations? Hallé and de Boysson-Bardies proposed that infants of 11 months, in contrast to infants of 7½ months, listen to words as potential sources of semantic content. This listening strategy may predispose them to adopt a more holistic listening strategy, thus interfering with their ability to detect and encode fine phonetic detail. Although this interpretation is of extreme interest, there is nothing about the task utilized by either Jusczyk and Aslin (1995) or Hallé and de Boysson-Bardies (1996) that requires the infants to listen for meaning, or even to listen for words. To perform successfully, all they have to do is to recognize and listen preferentially to a familiar acoustic form.

Werker, Cohen, Lloyd, Casasola, and Stager (1998) developed a task to more directly, and conservatively, address the question of whether and when infants use their full repertoire of perceptual sensitivities in a situation that requires the infant to use the more advanced skill of linking the label with an object. In this task, the "switch" procedure, infants are habituated to two word–object pairings and tested on their ability to detect a switch in the pairing. Infants of 14 months can rapidly learn to associate two dissimilar sounding words (*lif* and *neem*) to two different objects, and will show this knowledge by looking longer to a trial in which one of the familiar words is now paired with the object that had previously been associated with the other word. Infants younger than 14 months fail at this task. They can succeed in a simpler task in which they are familiarized to only a single word–object pairing and then required to detect a switch to a new word or a new object. Thus they have paid attention to, and learned about, both the word and the object, but they are unable to link the two unless there are nonarbitrary, amodal cues such as synchrony (see Gogate & Bahrick, 1998). It is, of course, the ability to detect an arbitrary linkage between a word and its referent that makes this task specific to word learning; the ability to detect an arbitrary linkage is not evident until 14 to 15 months (see Schafer & Plunkett, 1998, and Woodward, Markman, & Fitzsimmons, 1994, for similar age results—15 and 13 months, respectively—to those of Werker et al., 1998, using different procedures).

Stager and Werker (1997) then used the switch task and its simplified, single-object variant to directly test the question of whether infants at this age are able to use their fine phonetic discrimination capabilities when mapping words to objects. Surprisingly, although infants of 14 months easily learn to map two phonetically dissimilar words (*lif* and *neem*) onto two different objects and detect a "switch" when the word–label pairing is violated (Werker et al., 1998), they failed at this task when the phonetically similar words *bih* and *dih* were used. A series of control studies confirmed that infants of 14 months are capable of discriminating these two nonce words in a discrimination task that does not allow them to link the words with a nameable object. However, as soon as an object is presented along with the word, even if a mapping is not required (yet importantly, still possible), as in the single-object condition, infants of 14 months fail to distinguish the words. Younger infants, who are not yet able to form associative links and for whom this single-object condition is merely a discrimination task, do discriminate the minimally different words in this condition. Thus it appears that when infants listen to words as acoustic forms, discrimination of phonetically similar words is possible, but when they attempt to map the words onto meaning, they are no longer able to attend to the fine phonetic detail. For this reason, although associating words with objects is not necessarily equivalent to full referential understanding, we refer to this associative task when used with infants 14 months and older as a word-learning task.

A series of follow-up studies were conducted to assess the generalizability of the finding just reported. These studies confirmed that the difficulty infants of 14 months experience in linking similar-sounding words to two different objects is not restricted to this particular set of stimuli. Infants of 14 months still failed when less similar objects were used (Stager, 1999), when the syllable form was changed to make it a more standard word form (using a consonant–vowel–consonant syllable form—*bin* and *din*, rather than the consonant–vowel [CV]—*bih* and *dih*), when a voicing distinction was used rather than a place-of-articulation difference (*pin–bin*), and even when two features, voicing in addition to place, were used (*pin–din*; see Pater, Stager, & Werker, 1998, 2001).

Published studies with slightly older infants, however, yield a different pattern of findings. In a series of studies comparing infants' looking time to a known named word in comparison to a phonetically similar nonword (e.g., looking to a dog when the word *dog* is presented vs. when the word *bog* is presented), Werker and Pegg (1992) reported that infants of 18 to 19 months, but not younger, succeed under some testing conditions (see Werker & Stager, 2000, for more detail). More recently, a number of studies have been conducted assessing infants' responsiveness to mispronunciations of well-known words building on a word-recognition technique developed by Fernald and colleagues (Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998). Although recognition of well-known words likely involves different processes than does learning of new words, and although the testing procedures themselves differed in a number of respects, it is nonetheless interesting to consider these studies. In one study, Swingley, Pinto, and Fernald (1999) tested infants aged 24 months on their latency to fixate the matching visual target in response to a correct or incorrect label. It was found that although infants were delayed in fixating the matching target if the label and distractor contained the same initial consonant (e.g., *dog–doll*), the infants were not delayed when the label and distractor were rhymes that differed by only a minimally distinct initial consonant (e.g., *doll–ball*). More recently, Swingley and Aslin (2000; see also Fernald, McRoberts, & Swingley, in press) tested infants of

18 to 23 months of age on their latency to look to a match when a well-known word versus a phonetically similar "mispronounced" word was used (e.g., *baby–vaby*). Again, looking time to the match was significantly delayed when the mispronounced nonce word was presented in comparison to the correct pronunciation, also indicating that infants of 18 to 23 months have detailed representations of well-known words. In related work, Plunkett, Bailey, and Bryant (2000) tested whether it is recency of word learning that best predicts infants' success in distinguishing similar-sounding words. Some support was found for their hypothesis that infants 18 to 24 months of age represent more phonetic detail in words they have known for a long time than they do in recently learned words, but the overall pattern of results still indicated that infants of this age are sensitive to the fine phonetic detail distinguishing words.

The aforementioned studies all tested infants on the detail of the phonetic representation of known words in comparison to a mispronounced variant of that word, whereas the previous work by Stager and Werker (1997) tested infants on their ability to learn two new words that are phonetically similar. One other recent study tested infants in a laboratory setup on their ability to learn two similar-sounding words, and that was with older infants. Hoskins and Golinkoff (under review) briefly familiarized toddlers of 31 to 33 and 34 to 35 months of age to two sets of novel word–object pairings using phonetically similar words. After familiarization, the toddlers were tested on their ability to distinguish the phonetically similar words in a two-choice looking procedure. Infants in both age groups successfully learned both pairs of phonetically similar words, but infants 34 to 35 months of age performed more reliably than did the infants of 31 to 33 months.

We thus have two apparently contradictory sets of findings. On the one hand, there are a number of studies that report that infants of 11 to 15 months of age who are only beginning to learn words do not use their speech perception sensitivities in word-learning tasks (Hallé & de Boysson-Bardies, 1996; Kay-Raining Bird & Chapman, 1998; Pater et al., 1998; Stager & Werker, 1997) and some more naturalistic studies with even older children showing continuing confusion of similar-sounding words throughout the toddler and preschool period (Brown & Matthews, 1997; Eilers & Oller, 1976; Gerken, Murphy, & Aslin, 1995). On the other hand, there are a number of studies with infants 18 months and older—primarily in lexical access tasks—that suggest that infants are able to use all the perceptually available fine phonetic detail in word-recognition tasks (Swingley & Aslin, 2000; Swingley, Pinto, & Fernald, 1999; Werker & Pegg, 1992). How can we account for these differences?

There are several possible explanations. One is that the difference occurs because there is something qualitatively different about the infants of 18 to 24 months (e.g., vocabulary size, neighborhood density) that allows them, but not 14-month-old infants, to represent fine phonetic detail. If this explanation is correct, there should be an age difference in performance independent of the task used. A specific prediction, then, would be that if infants 18 months and older were tested on precisely the same task used by Stager and Werker (1997), the older infants should be unlike the younger infants, and should successfully learn the similar-sounding words. The other possibility is that it is not a difference in age or level of development that accounts for the two different sets of findings; rather it is something about the task or the exposure conditions that leads to differential results in the two bodies of research. Here it might be argued that the task used by Stager and Werker was somehow too difficult to allow infants to reveal an ability that was already present. A specific prediction would be that if the task were made easier, infants of all ages, including those at 14 months, should show success in learning similar-sounding words. The experiments presented herein were designed to begin to tease apart these two possibilities.

EXPERIMENT 1

It is well known that around 18 months, infants become much more accomplished word learners. The classically described word spurt in vocabulary acquisition (sometimes referred to as the naming explosion) is said to occur at, around, or shortly after 18 months (Bloom, 1973; Clark, 1973; Fenson et al., 1994; Nelson & Bonvillian, 1973). It is at about this same age that infants first begin to combine two words in their productions as well (Bloom, 1973; Nelson & Bonvillian, 1973). The comprehension vocabulary size of the child, which is typically advanced relative to production, is so great by this age that it becomes impossible for parents to indicate, on a parent report inventory, the words their child understands (Benedict, 1979; Fenson et al., 1994). Evidence of infants' expertise in word learning is shown in a number of other domains as well. For example, it is around 18 to 19 months that infants can reliably use social cues such as line of regard to ascertain just which of two objects a parent is labeling (Baldwin, 1993; Baldwin, Markman, Bill, Desjardins, & Irwin, 1996). It is also at around 18 to 19 months of age that many of the constraints that are thought to facilitate word learning, such as the whole-object assumption (Markman, 1987), taxonomic assumption (Markman & Hutchinson, 1984), mutual exclusivity (Markman, 1989; Merriman & Bowman, 1989), and others become functional. All of these skills coalesce to make the older infant a more proficient word learner than the younger infant.

We thus needed to test infants older than 18 to 19 months of age to ensure that they were proficient word learners. We chose the age of 20 months because of recent event-related potential (ERP) work we completed with Mills and colleagues (in prep; Prat, Stager, Mitchell, Adamson, & Sanders, 1999) that predicts that by 20 months infants should be beyond confusing similar-sounding words. In this work, Mills et al. found that although the ERP response to mispronunciations of known words at 14 months indicates confusion with known words, by 20 months of age the ERP response to mispronunciations of known words is like that to unknown words, indicating that the infants no longer confuse mispronunciations with correct pronunciations.

All infants were tested in the "switch" design, as developed by Werker et al. (1998). In addition, a parent report inventory of vocabulary size was collected for each infant. Even though the previous work to date has not revealed a consistent correlation between vocabulary size and ability to encode fine phonetic detail in words (Plunkett et al., 2000; Swingley & Aslin, 2000; Swingley et al., 1999), there are models of lexical acquisition that predict such a relation (see Beckman & Edwards, 2000). Connectionist models of lexical acquisition predict a change in detail detected and represented when the vocabulary size reaches a critical threshold (Plunkett, Sinha, Moller, & Strandsbury, 1992; Schafer & Mareschal, 2001), which results according to some because the phonological neighborhood density is increased (Charles-Luce & Luce, 1990, 1995; Metsala, 1999; Walley, 1993). According to others, vocabulary size is not related in a causal way to the ability to learn phonetically similar words, but might instead be indicative of some other underlying milestone that might allow infants to learn these words. For example, it might be an index of proficiency in word learning (see Beckman & Edwards, 2000, for a discussion of these alternatives). To the extent novice word learners fail to learn phonetically similar words because they have insufficient computational resources to allow them to attend to the fine phonetic detail (as argued by Stager & Werker, 1997, 1998), vocabulary size could serve as a proxy to help identify those infants who have moved from a novice to a more proficient status of word learning. A simple test of whether vocabulary size is related to minimal-pair word-learning ability will not distinguish these possibilities, but it will allow an understanding of whether any of the possibilities already outlined are plausible. For this reason, we collected vocabulary data on each infant.

Method

Participants. Sixteen 20-month-old infants completed this study, 8 girls and 8 boys (*M* age = 20 months, 20 days; range = 20 months, 5 days–21 months, 5 days). All participants in this and the next two studies were without apparent health problems, were at least 37 weeks gestation, and were exposed to English at least 70% of the time. An additional 18 infants were tested but were not included in the analyses because they were too fussy to continue ($n = 10$), they were not visible to the coder during at least one trial ($n = 3$), their parents interfered in some way ($n = 4$), or because no CDI information was received ($n = 1$).

Participants were recruited through visiting new mothers at BC Children's and Women's Hospital and by voluntary response to public service announcements. Participating infants were given an "Infant Scientist" T-shirt and diploma.

Stimuli. The audio stimuli were two nonsense consonant–vowel labels: *bih* and *dih*[1] recorded in infant-directed speech (IDS). IDS is effective in gaining and maintaining infant attention (Fernald, 1985; Werker & McLeod, 1989) and in facilitating word learning in infants (Fernald, McRoberts, & Herrara, 1991). The use of IDS also facilitates infant phonetic discrimination (Karzon, 1985). These stimuli differ only in the place of articulation of the initial consonant. An additional highly dissimilar nonsense label, *pok*,[2] was used during the pre- and posttest trials.

In a soundproof booth, a researcher recorded an English-speaking female producing several exemplars of each syllable in an infant-directed, rise–fall intonational phrase. Final stimuli comprised 10 exemplars of approximately 0.7 sec in duration each, with a 1.5-sec silent interval between exemplars, resulting in audio files of 20 sec in duration (see Stager & Werker, 1997, for more details).

Two objects (*crown* and *molecule*), which differed in both form and color, were used for the habituation and test trials (see Figures 1a and 1b). A store-bought, multicolored toy waterwheel (“spinner”) was used for both the pre- and posttests (see Figure 1c). All three objects were videotaped against a black background and then transferred to laser disk format. *Crown* and *molecule* were taped moving back and forth across the screen at a slow and constant velocity (*crown* = 15.59 cm/sec, *molecule* = 13.08 cm/sec). The spinner was filmed with the base remaining stationary while the wheel was moved around in a clockwise motion. At the distance tested, the objects take up a 13.5° vertical and 13° horizontal visual angle.

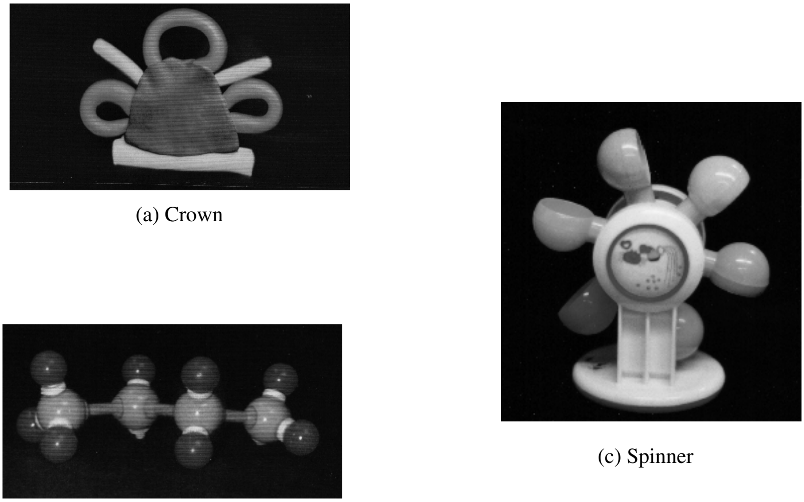
The stimuli are available on the Infancy Archives Web site at http://www.infancyarchives.com/. The video clips are stored as QuickTime movies and the audio files are in AIFF (Macintosh) and WAVE (IBM) format.

Apparatus. Testing took place in an 83" × 113.5" quiet room, which was dimly lit by a shaded 60-watt lamp situated 24 in. to the left of the infant at a 45° forward angle. The infant sat on the parent’s lap facing a 27-in. Mitsubishi CS-27205C video monitor that was approximately 46 in. from the infant. The audio stimuli were delivered at 65 dB, ± 5 dB, over a Bose 101 speaker located directly above the monitor. The monitor was surrounded by black cloth, which stretched the width and height of the room. The infants were recorded using a Panasonic AG 180 video camera. The lens of the video camera peeked out of a 2.5-in. hole in the black cloth located 10 in. below the monitor. As a masking control during testing, the parent wore Koss TD/65 headphones over which female vocal music was played from a Panasonic XBS portable stereo.

The experiment was controlled by a version of the Habit program, created by the Leslie Cohen laboratory at the University of Texas at Austin. The program

[1]These stimuli can be phonetically transcribed as [bI] and [dI].

[2]This stimulus can be phonetically transcribed as /pOk/.



(a) Crown

(c) Spinner

(b) Molecule

FIGURE 1 (a) Crown, (b) Molecule, and (c) Spinner objects.

was run on a Power Mac 8500/120 linked with a Sony LDP-1550 laserdisc player. The visual stimuli and the audio stimuli, played from a digitized audio file on the computer, were synchronized and sent to a monitor and speaker in the testing room.

The experimenter, who was blind to the audio stimuli being presented and to whether a trial was a habituation or test trial, monitored the infant's looking times via a closed-circuit television system from an adjacent testing room. A designated key was pressed on the computer keyboard during infant looks, which the Habit program recorded. The video record was used for subsequent reliability coding.

Procedure. After the procedure was explained to the parent or parents and they had signed a consent form, the infant and one parent were taken to the testing room and positioned for the experiment. The experimenter returned to the observation room to begin the procedure. The infant was assigned to participate in a preselected order, chosen from a randomly sequenced list of possible orders. One male and one female infant were assigned to each of the eight possible orders. These orders counterbalanced the order of test trial (same before switch/switch before same) and the type of switch between the test trials (switch in object/switch in word).

The infants were tested using a modified habituation paradigm, identical in structure to that used by Werker et al. (1998), but modified for trial duration (increased from 14 sec to 20 sec) and habituation criterion (adjusted from a decrement of 65% in Stager & Werker, 1997, to 50% here) according to parameters deemed necessary by Casasola and Cohen (2000) for the procedure to work in this age group. Each trial began when the infant fixated on a flashing red light. On the first trial, infants were presented with a pretest stimulus, and the label *pok* paired with the spinner. During the habituation phase the infant was shown two word–object pairs (e.g., Pair A: word *dih* and object *molecule,* Pair B: word *bih* and object *crown*). Every block of four trials contained two instances of each word–object pairing presented in a random order (ABAB, ABBA, etc.). Looking time was calculated online, and when the average looking time across a four-trial block decreased to the preset criterion, the habituation phase ended. The infants participated in a minimum of 8 and a maximum of 24 habituation trials.

Following habituation, the test phase began. One test trial was a "same" trial in which one of the pairings presented in the habituation phase was presented again (e.g., Pair A). The other trial, the "switch" trial, contained a familiar word and familiar object but in a novel pairing (e.g., label from Pair A with object from Pair B). The order of presentation of the trials was counterbalanced across participants. It was expected that if infants had learned the pairing they would detect the switch and look longer during the switch than the same trial. In the final posttest trial the child was again presented with *pok* and the spinner. It was expected that if infants were still involved in the experiment, looking time would recover to near pretest level during this final trial.

Communicative development inventory. Parents were either mailed a copy of the Toddler version of the MacArthur Communicative Development Inventory (CDI) in advance or given one when they visited the lab. All parents were given the same brief instructions on how to complete the CDI and were asked to complete it within 1 week of testing. This form asks parents to indicate, from among a list of 680 words, all the words their child produces (comprehension vocabulary is too large to estimate reliably at this age). The CDIs were later scored for both the raw number of words produced and for the percentile ranking of each child. The percentile ranking at each age is calculated separately for girls and boys because, as a group, females tend to be slightly advanced relative to males in vocabulary development.

Reliability coding. To determine the reliability of the experimenter's coding, a second trained coder scored the looking times of all of the usable participants offline. Online scores were rounded to the nearest 0.1 sec. Offline scoring was also done to the nearest 0.1 sec. A Pearson product–moment correlation of online and offline scores had to be equal to or greater than .95 for the data to be considered reliable. This level of agreement was reached for participants in all three experiments.

Results

To ensure that infants maintained interest throughout the experiment, a preliminary analysis was conducted to compare looking time on the pretest versus posttest trial. As predicted, this 2 (sex: female vs. male) × 2 (trials: pretest vs. posttest) mixed analysis of variance (ANOVA) yielded no main effects or interaction. There was a significant drop in looking time across the habituation phase. A 2 (sex: female vs. male) × 2 (trial block: first four habituation trials vs. last four habituation trials) mixed ANOVA was significant, $F(1, 14) = 70.12$, $p < .001$ ($M_{firstblock} = 17.84$, $M_{lastblock} = 9.55$).

The main set of analyses addressed infants' performance on the test trials. A 2 (sex: female vs. male) × 2 (test trials: same vs. switch) mixed ANOVA revealed a significant main effect for test trials, with the infants looking longer to the switch trial than to the same trial, $F(1, 14) = 5.416$, $p = .035$ ($M_{switch} = 12.51$, $M_{same} = 9.55$). There was no main effect for sex and no interaction. The same pattern of results was obtained for both the 10 habituators and the 6 nonhabituators. Thus, the 20-month-old infants exposed to the minimally different words *bih* and *dih* did notice the switch in the word–object pairings (see Figure 2).

To ascertain whether vocabulary size is related to relative success on the word-learning task, we correlated productive vocabulary size, as measured by the CDI (see Table 1 for vocabulary statistics), to performance on the minimal-pair associative word-learning task as indicated by the switch versus same

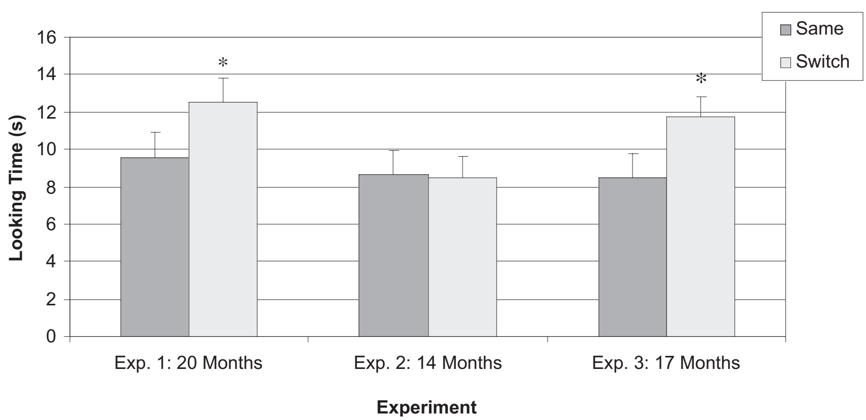


FIGURE 2 Mean looking times to test trials.

TABLE 1
Descriptive Statistics for Vocabulary Scores

Vocabulary Measures	*Age Group* 14 *M*	14 *SD*	14 *Range*	17 *M*	17 *SD*	17 *Range*	20 *M*	20 *SD*	20 *Range*
Raw comprehension score	125	68.54	18–278	207.31	70.28	30–280	Comprehension scores are not available on the Toddler form.		
Raw production score	20.56	22.83	0–81	77.69	84.09	3–249	194.69	181.41	31–628
Percentile comprehension score	43.75	26.17	5–90	Comprehension scores are not normed for 17-month-olds.			Comprehension scores are not available on the Toddler form.		
Percentile production score	42.81	31.46	0–95	40.56	33.04	5–90	49.56	32.12	10–99

difference score. A box-plot analysis of the production scores showed that one score was an outlier. Excluding this case, raw production scores and the difference scores in looking times to “switch” and “same” were compared. One-tailed tests were used for all correlation analyses in this and the next two experiments because of the a priori hypothesis that performance and vocabulary size are positively correlated. The Pearson correlation was not significant for raw or percentile production scores.

Discussion

In contrast to the results reported by Stager and Werker (1997) with infants of 14 months, the results from Experiment 1 suggest that by 20 months of age infants are able to learn phonetically similar words. These results are concordant with those from the ERP study (Mills et al., in preparation; Prat et al., 1999), the preliminary reports by Werker and Pegg (1992), and the lexical access literature (Swingley & Aslin, 2000; Swingley et al., 1999), which show that infants 18 to 24 months of age recognize mispronunciations of well-known words. The current work extends those findings to show that by 20 months of age infants are able to encode and represent fine phonetic detail even when learning new words. These results thus argue against the notion that it is the recency of exposure (Plunkett et al., 2000) that accounts for the deficit seen in younger infants.

It is perhaps informative that at 20 months of age there is no correlation between performance on the CDI and the minimal-pair word-learning task. This kind of finding could be taken as evidence against either a threshold account or a word-learning proficiency account of why some infants, but not others, can learn minimally different words. As such, it could be seen as evidence against the notion that there is something different about the older infant in comparison to the younger infant that facilitates word learning, and would suggest instead that perhaps the testing conditions used with the younger infants were not sufficiently sensitive to reveal an underlying ability. Consistent with this possibility, there were differences in the implementation of the procedure used in Experiment 1 in comparison to that used with infants 14 months of age by Stager and Werker (1997), which could have affected the results. Thus, before concluding that there is in fact an age-related shift in infants' ability to learn phonetically similar words, it was essential to test a group of 14-month-old infants using precisely the same setup as that in which infants of 20 months succeeded.

EXPERIMENT 2

The purpose of this experiment was to determine whether infants 14 months of age might be able to link phonetically similar words to two different objects if tested under precisely the same conditions under which older infants succeeded. There were two important differences between Experiment 1 and the testing conditions used by Stager and Werker (1997). First, in Experiment 1, there was greater exposure time, with a trial duration of 20 sec versus the previous 14 sec, and a habituation criterion of 50% rather than 65%. Second, in their work in which infants of 14 months failed to learn two phonetically similar names for two different objects, Stager and Werker used two objects that could be criticized for being too similar. Although the objects were different in shape, both were made from identical quantities of each of three colors of FIMO clay (red, yellow, and blue). The objects used in Experiment 1 differed both in color and in shape (see Figures 1a and 1b). A number of studies have shown that when children between 1- and 3 years of age are taught a new label for an object, they are more likely to generalize that label to other objects that are perceptually similar to the labeled object than they are to objects that are perceptually dissimilar (Diesendruck & Shatz, 1997; Taylor & Gelman, 1988; Tomasello, Mannle, & Werdenschlag, 1988; Waxman & Senghas, 1992). It is thus possible that it was the greater physical dissimilarity in the objects, rather than age, that allowed the infants in Experiment 1 to succeed.

To address these two potential differences, in Experiment 2 infants 14 months of age were tested on their ability to learn phonetically similar words using precisely the same parameters and stimuli that were used with the infants of 20 months in Experiment 1. Again, the CDI was used to test for a relation between vocabulary size and performance on the word-learning task with this younger population.

Participants

Sixteen 14-month-old infants completed this study, 8 girls and 8 boys (*M* age = 14 months, 11 days; range = 13 months, 29 days–14 months, 24 days). An additional 24 infants were tested but were not included in the analyses because they were fussy ($n = 12$), were not visible to the coder during at least one test trial ($n = 4$), their parents interfered in some way ($n = 7$), or due to experimenter error ($n = 1$).

Stimuli and Apparatus

The stimuli, apparatus, and procedure were identical to those reported in Experiment 1. As in Experiment 1, parents of all infants were asked to fill out the MacArthur CDI. Standard procedure is for the Infant version of the CDI to be used with infants up to 16 months of age and for the Toddler version to be used with older infants. Thus, in this experiment, the parents were asked to fill out the Infant version of the CDI. This version asks parents to indicate, from a list of 396 words (in comparison to the 680 words on the Toddler version), which of the words listed their child understands (one column), and which of the words their child produces (a second column). Because the vocabulary size is typically smaller for infants of this age, it is possible to collect reliable data from parents on comprehension vocabulary (Fenson et al., 1994).

Results

The preliminary analysis comparing infant looking times on the pretest and posttest trials revealed no significant main effects or interactions confirming that infants had not lost interest in the task. The 2 (sex: female vs. male) × 2 (trial block: first four habituation trials vs. last four habituation trials) mixed ANOVA of the habituation phase revealed the expected main effect for trial block, $F(1, 14) = 135.422$, $p < .001$ ($M_{firstblock} = 16.40$, $M_{lastblock} = 7.82$).

The primary analysis assessing whether infants noticed a switch in the word–object pairing, a 2 (sex: female vs. male) × 2 (test trials: same vs. switch) mixed ANOVA revealed no main effect for trials ($M_{same} = 8.66$, $M_{switch} = 8.51$) or gender, and no significant interaction (see Figure 2).[3] Moreover, of the 16 infants, 9 looked longer to the switch trial and 7 looked longer to the same. Thus there was no evidence that, as a group, infants of 14 months can learn to associate the two phonetically similar words to two different objects.

Two sets of correlations were run comparing vocabulary size (production and comprehension), as measured by the CDI, to performance on the minimal-pair associative word-learning task (see Table 1 for vocabulary statistics). Again, one-tailed tests were used for all correlations. The correlation between raw comprehension scores (actual number of words understood) and performance on the word-learning task revealed a trend toward a relation, $r(14) = .403$, $p = .061$. The correlation between percentile comprehension score (using the CDI age × gender norms) was significant and similarly suggestive, $r(14) = .448$, $p = .041$. A box-plot analysis of the raw production scores revealed that one score was an outlier. Excluding this outlying case, the correlation between number of words produced and performance on the word-learning task was also significant, $r(13) = .656$, $p = .004$. The correlation between percentile production score and the difference scores also reached significance, $r(14) = .509$, $p = .02$.

Discussion

The use of physically disparate objects and increased exposure time did not improve performance in this procedure in this age group. Infants 14 months of age, as a group, were unable to learn to associate two phonetically similar words with two different objects. The analysis of the CDI data indicates that not all infants of 14 months perform equally poorly at learning minimally different words, however. Those infants who have larger vocabularies at 14 months are better able to learn phonetically similar words than are those infants who are not yet producing as many words. The relation between vocabulary production scores and performance on the word-learning task was significant for both the raw number of words produced and for the percentile ranking. The relation between vocabulary comprehension scores was similarly suggestive but not as strong.

In conclusion, then, the results from Experiment 2 show that there is an age difference in performance even when precisely the same testing conditions are used. Moreover, in this younger group of infants there is a significant correlation between vocabulary size and performance on the word-learning task. These findings argue against the notion that it was task conditions that prevented infants of 14 months from performing successfully in the original Stager and Werker (1997) work and suggest instead that there might be something different between the

[3]Of the 16 infants tested, 12 reached habituation criterion. An analysis of only these 12 infants also revealed no main effect for test trials or gender and no significant interactions.

abilities of younger and older infants to learn minimally different words. Moreover, this ability might be indexed successfully by vocabulary size.

EXPERIMENT 3

The first two experiments confirm that there is indeed a change between infants of 14 and 20 months of age in their ability to learn to associate phonetically similar words with different objects in a brief laboratory setting. Infants of 20 months of age, most of whom would be classified as proficient word learners, are able to learn phonetically similar words, whereas infants of 14 months, most of whom are still novice word learners, are not. The analysis of the CDI data shows that there is a correlation between vocabulary size at 14 months and performance in the word-learning task, whereas at 20 months there is not. In this experiment we tested 17-month-old infants. This age is of interest because it is slightly younger than that previously reported in the literature for success in learning phonetically similar words, so if infants of this age can succeed, it will push down the threshold at which successful performance on this type of task is possible. Second, by selecting an age at which infants are likely in transition in their word-learning abilities, we should have a larger sample of infants who are in pre- and postvocabulary spurt and will thus be in a position to test more directly if there is a relation between vocabulary size and performance on the minimal-pair word-learning task.

Participants

Sixteen 17-month-old infants completed this study, 8 girls and 8 boys (*M* age = 17 months, 19 days; range = 17 months, 0 days–18 months, 7 days). An additional 18 infants were tested but were not included in the analyses because they were too fussy to complete the experiment ($n = 11$), were not visible to the coder during at least one test trial ($n = 3$), or due to parental interference ($n = 4$).

Stimuli and Apparatus

The stimuli, apparatus, and procedure were identical to those reported in Experiments 1 and 2. Although it is standard protocol to use the Toddler version of the CDI with infants of this age, pilot work in our laboratory revealed that the Infant version is more appropriate for many infants in our community at this age. Thus, we asked parents to complete both the Infant and Toddler versions if they could. We used the Infant version to estimate receptive vocabulary and the Toddler version to estimate productive vocabulary. The parents of infants with very small productive vocabularies chose not to complete the Toddler version and handed in only the Infant version. For those 5 infants, we used the Infant version to estimate productive vocabulary.

Results

The preliminary 2 (sex: female vs. male) × 2 (trials: pretest vs. posttest) mixed ANOVA yielded no main effects or interactions, confirming that infants did not become less alert during the course of the experiment. The 2 (sex: female vs. male) × 2 (trial block: first four habituation trials vs. last four habituation trials) mixed ANOVA of the habituation phase again showed the expected main effect for trial block, $F(1, 14) = 110.375$, $p < .001$ ($M_{\text{firstblock}} = 18.14$, $M_{\text{lastblock}} = 10.04$).

The primary 2 (sex: female vs. male) × 2 (test trials: same vs. switch) mixed ANOVA revealed a main effect for test trials, with the infants looking significantly longer to the switch trial than to the same trial, $F(1, 14) = 4.643$, $p = .049$ ($M_{\text{same}} = 8.50$, $M_{\text{switch}} = 11.72$). There was neither a main effect for gender nor an interaction. The same pattern of results was found for both the nine habituators and the seven nonhabituators. Thus, the 17-month-old infants exposed to the minimally different words *bih* and *dih* did notice the switch in the word–object pairings (see Figure 2).

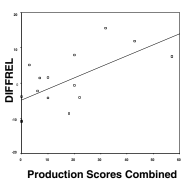
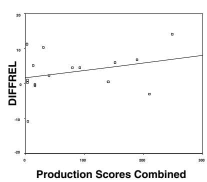
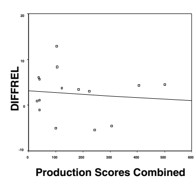
Two sets of correlations were run, one comparing comprehension vocabulary and one productive vocabulary size, as measured by the CDI (see Table 1 for vocabulary statistics), to performance on the minimal-pair associative word-learning task, as measured by the difference scores in looking times to switch and same. The comprehension measures have yet to be normed for this age group, so a correlation involving comprehension percentile scores is not reported. A box-plot analysis of the raw comprehension scores showed that one score was an outlier. Excluding this case, comprehension scores and the difference scores were compared. Again, one-tailed tests were used. The correlation approached significance, $r(13) = .408$, $p = .065$. No other correlation between vocabulary size and performance was significant at 17 months.

Discussion

The results from the infants aged 17 months of age are very revealing. Like the infants 20 months of age, and unlike those at 14 months, they are able to rapidly learn to associate two phonetically similar words with two different objects. Thus, by 17 months of age infants are able to encode fine phonetic detail when learning new words. That they could do so within a very short exposure period argues against both an amount of exposure (processing) explanation and a recency of learning explanation. Instead, the pattern of results suggests there is something different about infants at 17 months of age as a group in comparison to infants at 14 months that enables them to succeed in this task. The pattern of correlations to vocabulary size is intermediate between that seen at 14 months and that seen at 20 months of age. At 14 months, both productive vocabulary size (raw scores and percentiles) and percentile comprehension scores correlate with performance on the word-learning task. At 20 months of age, there is no relation of any kind between vocabulary size and performance on the word-learning task. At 17 months, there is a correlation between comprehension (but not productive) vocabulary and performance on the word-learning task that approaches significance (see Table 2).

Exploring the relation between vocabulary size and minimal-pair word learning. In this section we present a set of exploratory, post hoc analyses that were conducted to provide further insight into the possible meaning of the correlation found between vocabulary size and word learning in the younger but not the older infants. Specifically, this pattern of correlations

TABLE 2
Correlations Across the Three Age Groups

Analyses	*14-Month-Olds*	*17-Month-Olds*	*20-Month-Olds*
Correlated CDI comprehension scores with the difference score from the task	$r(14) = .403$, $p = .061$	$r(13) = .408$, $p = .066$	Comprehension scores are not available on the Toddler form.
Correlated CDI production scores with the difference score from the task	$r(13) = .656$, $p = .004$	$r(14) = .301$, $p = .128$	$r(13) = –.099$, $p = .362$
Correlated CDI percentile rank comprehension scores with difference score from the task	$r(14) = .448$, $p = .041$	Comprehension scores are not normed for 17-month-olds.	Comprehension scores are not available on the Toddler form.
Correlated CDI percentile rank production scores with difference score from the task	$r(14) = .509$, $p = .022$	$r(14) = .274$, $p = .152$	$r(14) = –.045$, $p = –.434$
Scatterplot with regression line comparing raw production scores and the difference score			

Note. CDI = Communicative Development Inventory.

raises the possibility that there may be some threshold of vocabulary size below which a correlation holds between words understood or produced and minimal pair–word learning performance, and above which no relation holds. Because several of the models in the literature (see Beckman & Edwards, 2000, for a review) propose such a relation, we conducted some exploratory analyses to empirically search for a threshold.

We began our post hoc exploration using the value of 50 words in production as measured by the CDI because of the often reported relation between that number of known words and the onset of the naming explosion (Benedict, 1979; Bloom, 1973; Nelson & Bonvillian, 1973; for a review see Hoff-Ginsberg, 1997). Our strategy was simply to start by examining performance on the switch in comparison to the same trials in infants with more than or less than 50 words in their productive vocabularies, and then systematically go up and down from 50 words until we found the threshold yielding the most significant difference. The sharpest cutoff was found at 25 words. Those infants with productive vocabularies of less than 25 words looked equally to same and to switch trials, whereas those infants with productive vocabularies of more than 25 words looked significantly longer to the switch trials, $t(28) = -3.747$, $p = .001$ ($M_{\text{same}} = 8.39$, $M_{\text{switch}} = 12.53$; see Figure 3). The latter group includes all of the infants 20 months of age, nine of the infants of 17 months, and four of the infants at 14 months of age.

A similar pattern of data was seen in our post hoc search for a comprehension threshold. Here the sharpest cutoff was obtained at 200 words. Those infants who are reported to understand less than 200 words do not succeed in the word-learning task, whereas those infants with reported comprehension vocabularies of more than 200 words do, $t(11) = -3.134$, $p = .01$ ($M_{\text{same}} = 7.94$, $M_{\text{switch}} = 12.51$; see Figure 4). This time the latter group included 10 infants 17 months

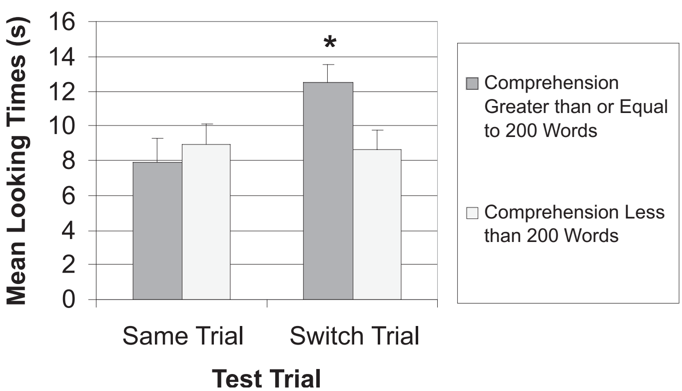


FIGURE 3 Looking times to "same" and "switch" trials by comprehension vocabulary size.

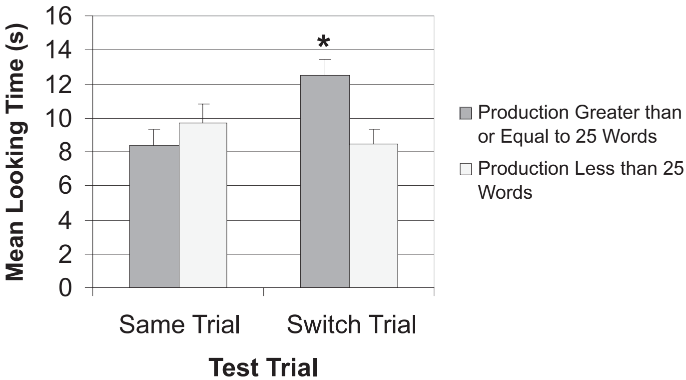


FIGURE 4 Looking times to "same" and "switch" trials by productive vocabulary size.

of age and 2 infants of 14 months.[4] Infants of 20 months are not included in this analysis because there is no comprehension measure on the Toddler version of the CDI.

With a significant correlation between vocabulary size and word learning, an empirical search for a threshold will, by necessity, yield a value that will discriminate between the two groups. The values that were uncovered are, nonetheless, of interest. The current literature suggests a relation between a 50-word productive vocabulary size, as measured by both diary studies (Bloom, 1973; Clark, 1973; Nelson & Bonvillian, 1973) and parental checklists (Fenson et al., 1994) as predicting the onset of the naming explosion. Although the measurement tool used may lead to differences in estimated vocabulary size, our finding that a productive vocabulary substantially smaller than 50 words (25 words as measured by the CDI) predicts ability to learn minimally different words could be theoretically important. It raises the hypothesis that the ability to attend to fine phonetic detail might precede, and even be a mechanism that enables, a change of rate in word learning, rather than the threshold vocabulary size being the key to attending to fine phonetic detail. This will be of great interest to explore in future work.

The 200-word value reported for comprehension is also of interest. In previous studies that failed to find a consistent relation between vocabulary size as measured by the CDI and online word recognition (Plunkett et al., 2000; Swingley & Aslin, 2000; Swingley et al., 1999) the infants were reported to have receptive vocabularies of at least 200 words. This finding, together with our results, would suggest that vocabulary size is only consistently predictive of the phonetic detail used in lexical learning and recognition tasks when the child is first assembling a vocabulary.

[4]The 10 infants who had larger productive vocabularies at 17 months included all 9 infants who had larger comprehension vocabularies, and the 2 infants at 14 months who had larger productive vocabularies were a subset of the 4 infants of this age who had larger comprehension vocabularies.

After the vocabulary, as measured by either production or comprehension indexes, passes some critical threshold, the relation is no longer consistent.

GENERAL DISCUSSION

In summary, across a series of three studies we have found that, although infants of 14 months have difficulty learning phonetically similar words, by 17 and 20 months of age infants can learn phonetically similar words with only minimal exposure and with no contextual support. The finding with infants at 14 months of age replicates that reported by Stager and Werker (1997; Pater et al., 1998, 2001), and rules out the possibility that the lack of success at 14 months was due to simple procedural factors such as the amount of exposure during the familiarization phase or the physical similarity of the two objects to which infants were to associate the word forms. With a significantly increased trial duration and a stricter habituation criterion, and with the use of new objects that are visually much more distinct than those used by Stager and Werker, infants of 14 months still failed to learn to pair minimally distinct words with the two different objects, whereas infants of both 17 and 20 months of age succeeded.

When considered in the context of previously reported work in the field, these findings suggest that it is only during a brief window of development that children confuse phonetically similar words in a word-learning procedure. At 7 to 9 months of age infants easily discriminate minimally different words in word-segmentation (Jusczyk & Aslin, 1995) and word-discrimination (Stager & Werker, 1997) tasks. By 17 months of age infants easily learn and discriminate minimally different words in word-learning (Experiments 3 and 2, this study; Plunkett et al., 2000) and mispronunciation-detection tasks (Fernald et al., in press; Swingley & Aslin, 2000; Swingley et al., 1999; Werker & Pegg, 1992). However, in between those ages, when they are just beginning to move beyond recognizing word forms to actually linking word forms with objects and events in the world, infants have difficulty learning phonetically similar words (Eilers & Oller, 1976; Hallé & de Boysson-Bardies, 1996; Stager & Werker, 1997, 1998; Werker & Pegg, 1992). This difficulty is apparent even when both the amount of exposure to the word–object pairings and the physical dissimilarity of the objects are increased.

These results shed some light on the disagreements in the literature. First, they rule out the possibility that infants need to know words well (e.g., Barton, 1978, 1980) or have not just recently learned them (Plunkett et al., 2000) to be able to distinguish them from minimally different words. The infants 20 and 17 months of age in this study did not know the newly learned words well, yet they were able to successfully detect a mismatch in a word–object pairing in the "switch" design. The results from this study also help explain the fact that previous reports using the mispronunciation detection task have failed to find a positive correlation between vocabulary size and task performance. In previous studies in which no, or only inconsistent, correlations were found, the infants tested were 18 months of age and older and had larger productive vocabularies (Fernald et al., in press; Plunkett et al., 2000; Swingley & Aslin, 2000; Swingley et al., 1999). Our results revealed a correlation between minimal-pair word learning and vocabulary size only with younger infants and only with infants with smaller vocabularies as measured by the CDI.

Our results also add to the literature by supporting the notion that there might be some kind of threshold vocabulary size lower than that typically associated with the onset of the word spurt that predicts infants' ability to learn phonetically similar words. How might such a threshold operate? One view, as raised earlier, is that a threshold vocabulary size could act as a causal force in leading to better performance on learning similar-sounding words. According to this logic, increases in vocabulary size are accompanied by increases in density of the phonological neighborhood, resulting in an increasing number of words in the lexicon that have similar phonological properties (e.g., more rhyming or alliterative words). To distinguish these words from one another the child is forced to elaborate the phonetic distinctions among words (Walley, 1993; see also Charles-Luce & Luce, 1990, 1995). The plausibility of this explanation is supported by connectionist models that show that when a sufficient vocabulary size is attained, a network (or lexicon) will reorganize so that the representations that distinguish phonetically similar words become more exact (Metsala, 1999; Metsala & Walley, 1998; Plunkett et al., 1992; Schafer & Mareschal, 2001).

The other alternative raised earlier is that the threshold vocabulary size may serve as an index of proficiency at word learning rather than as a causal mechanism itself. The logic here is that children who are better word learners, as indexed by attainment of a critical vocabulary level, have attentional resources freed up to attend to the fine phonetic detail in the word-learning task. Because they are better word learners they tend to know more words (have passed some threshold vocabulary size) and are better able to detect and represent the fine phonetic detail in those words. It is impossible, with the current data, to fully disambiguate these two possible explanations for the finding of a threshold effect. We would suggest, however, that without strong evidence to support the threshold as causal mechanism account, it is more prudent to assume the threshold is not absolute, but is merely an index of relative word-learning ability. Indeed, in our sample there were many infants with vocabularies larger than the threshold who did not learn the minimally different words and many with smaller vocabularies who did. Moreover, an exploratory analysis of all three age groups of infants on their normed percentile scores on the production portion of the CDI revealed a significant correlation ($r = .274$, $p = .03$, one-tailed), and this was still significant with group age partialed out ($r = .2364$, $p = .04$, one-tailed). These correlations show that infants who have relatively larger vocabularies at each age are better able to learn the minimally different words. These correlations are consistent with the notion that any cutoff score obtained is likely an index of, rather than a causal force in, relative word-learning ability.

How do these results map onto general theories of the relation between perceptual skills and word-learning abilities? We raised two possible explanations earlier for why the infants 14 months of age in Stager and Werker (1997; Pater et al., 1998, 2001; see also Hallé & de Boysson-Bardies, 1996, with infants at 11 to 12 months) had failed to learn minimally different words whereas older infants, tested primarily in lexical access tasks, had succeeded at distinguishing known words from minimal-pair mispronunciations (Fernald et al., in press; Swingley & Aslin, 2000; Swingley et al., 1999). One possible reason is that the difference in results stems from development: There is something different about older infants in comparison to younger infants that makes it possible for the older infants to learn and distinguish minimally different words. The other possibility is that it is not a difference in development that accounts for the different findings that have previously been reported in the literature; instead it is a difference in task demands. In the experiments reported in this article, we took a number of steps to address this possibility, and found that even with task demands simplified, younger infants still failed. Admittedly, it still remains an open question as to whether infants at 14 months would pass or fail to distinguish well-known words from minimal-pair foils in an online recognition task such as that used by Swingley and Aslin (2000), or whether there might be other potentially more sensitive ways to measure the phonetic detail of newly learned words than can be revealed by the switch procedure. Nevertheless, our results showing a robust effect of age and vocabulary size on minimal-pair word learning in the switch task are most consistent with a developmental explanation in which there is something different about older infants that allows them, but not younger infants, to succeed at the task.

What is it that is different in the older infant? At least three alternatives can be considered. One is that older infants utilize a different learning mechanism than do younger infants, that is, that there is a discontinuity in the processes by which they encode words. A second is that infants must construct a new representation of the words they hear when they are attempting to map sound onto meaning. According to this approach, which advocates a discontinuity in the representation, the perceptual representations formed from listening experience during infancy are not directly used in word-learning tasks; instead the infant must begin anew in constructing lexical representations. A third approach, and the one that we favor, is that there is a continuity in both the learning mechanisms that the infant relies on and the perceptual representations established from listening experience in infancy, but that the computational demands of linking words to meaning are so great for the novice word learner that he or she cannot attend as closely to the fine phonetic detail that is available, leading to incomplete information uptake. Each of these possibilities, and the rationale for our choice, is discussed next.

Although hypothetically possible, there is virtually no evidence to support the notion that there might be a different learning mechanism used by older than younger infants. Rather, there are excellent arguments in favor of the notion of a single learning mechanism, and there are excellent models of how a single learning mechanism could nonetheless yield a difference in the amount of detail available in the representation. For example, an incremental learning approach hypothesizes that individuals of all ages learn the same way, but that all need repeated exposure to a word to build up a detailed phonetic representation of it (Gerken et al., 1995; Plunkett et al., 1992). In these and other connectionist models, a single learning mechanism operates throughout, but the amount of detail in the representation varies in a nonmonotonic fashion as a function of the amount of exposure to both the word and to the word–object pairing (Schafer & Mareschal, 2001) in relation to the words already in the vocabulary (Metsala, 1999). In this way there can be a continuity in the underlying learning mechanism, but also differences in the amount of detail available in the representation. Importantly, these models do not go so far as to predict different representations used for perceptual versus lexical processing. Instead, they simply assume that the amount of detail available in the representation varies depending on exposure.

The strongest discontinuity models are those in which it is argued that the representation used in lexical (word-learning) tasks is distinct from the representation used in perceptual tasks (e.g., Brown & Matthews, 1997; Keating, 1984, 1988; Rice & Avery, 1995; Shvachkin, 1948/1973). All these models share the feature of requiring new phonological representations, distinct from those used in perception, to be assembled after the child begins to learn meaningful words. They argue that these two distinct representations continue even after word learning is complete and thus predict less phonetic detail in word recognition than in speech-perception tasks.

We adhere to a developmental difference explanation, but assume a continuity in both the learning mechanism and in the final underlying representation. According to our line of reasoning, perceptual analysis of the incoming acoustic information is a necessary first step in word recognition (e.g., see Jusczyk, 1994), thus the phonetic detail detected during this perceptual analysis must be available to the infant. We thus propose that the underlying representation used in both prelexical speech-perception tasks and in lexical-learning tasks is identical, but the infant's ability to utilize all of the information in that representation is compromised through some other limiting fact. In their previous work, Stager and Werker (1997; see also Werker & Stager, 2000) proposed that the task of linking words with objects is difficult for the novice word learner (which is what the infant of 14 months is). Because it is computationally demanding, infants—even though utilizing the same learning mechanisms—have fewer attentional resources to devote to listening carefully to the sound shape of words. Were they able to devote more resources to listening, we would argue that they would be able to pick up the finest level of detail, as is evident in perceptual tasks in infants of the same age. However, because the task involves linking two arbitrary representations—one of the word form and the other of the referent—the computational resources are not available and something has to give. In our work, it is the phonetic detail in the words that the infant has trouble attending to closely. In other work, it is the features of the events that the infant misses (see Casasola & Cohen, 2000). This model can be seen to share some features with an incremental learning approach. It differs, however, in that the difficulty is explained not on the basis of amount of exposure, but on the basis of the attentional resources available to a younger versus an older infant even in the face of equivalent amounts of exposure.

This type of argument is consistent with work in other domains in which it has been shown that the details infants attend to when learning new relations vary depending on overall task demands (see Cohen, 1998; Cohen & Cashon, 2001; Subrahmanyam, Landau, & Gelman, 1999). According to this argument, the difficulty that the novice word learner faces is not one of having to develop new learning mechanisms or of having to construct a new, lexical-based representation. Instead, the difficulty the novice word learner faces is one of being able to detect and encode the detail that is perceptually available at the same time that he or she is attempting to link a newly heard word with an unnamed object. This explanation predicts that the finest level of detail available in lexical tasks is that which is already specified and represented in established perceptual representations. We are currently testing this prediction. If it proves to be correct, this model would permit a single representation of the sound shape of words to be used in both speech perception and word-learning tasks, but with differential access to all the information in that representation at different points in development.

SUMMARY

In summary, in this series of three studies we have found that there is an age-related shift in minimal-pair word-learning performance during the first half of the second year of life. Even with increased exposure time and physically quite dissimilar objects, novice word learners are unable to reliably learn phonetically similar words in the switch design. Yet, under precisely the same learning conditions, older infants and those with larger vocabularies succeed. These data provide strong suggestive evidence that there is something different about the way an older, more experienced word learner approaches the word-learning task that allows him or her to listen carefully to the fine phonetic detail distinguishing one word from another, and raises the possibility that an ability to attend to fine phonetic detail in words is one of the factors that leads to an increase in the rate of vocabulary acquisition. The precise nature of the underlying mechanism that allows for this qualitative change in performance awaits further research.

ACKNOWLEDGMENTS

This research was supported by a Natural Sciences and Engineering Research Council grant (A-81103) and a Canada Research Chair to Janet F. Werker, NSERC graduate fellowships to Kathleen M. Corcoran and Christopher T. Fennell, and a Killam Graduate Fellowship to Christine L. Stager.

We would like to thank all the parents and infants who so generously participated in this research.

REFERENCES

Baldwin, D. A. (1993). Infants' ability to consult the speaker for clues to word reference. *Journal of Child Language, 20,* 394–419.

Baldwin, D. A., Markman, E. M., Bill, B., Desjardins, R. N., & Irwin, J. M. (1996). Infants' reliance on a social criterion for establishing word–object relations. *Child Development, 67,* 3135–3153.

Barton, D. (1978). *The role of perception in the acquisition of phonology.* Bloomington: Indiana University Linguistics Club.

Barton, D. (1980). Phonemic perception in children. In G. H. Yeni-Komshian, J. F. Kavanagh, & C. A. Ferguson (Eds.), *Child phonology: Vol. 2. Perception* (pp. 97–116). New York: Academic.

Beckman, M. E., & Edwards, J. (2000). The ontogeny of phonological categories and the primacy of lexical learning in linguistic development. *Child Development, 71,* 240–249.

Benedict, H. (1979). Early lexical development: Comprehension and production. *Journal of Child Language, 6,* 183–200.

Best, C. T., McRoberts, G. W., LaFleur, R., & Silver-Isenstadt, J. (1995). Divergent developmental patterns for infants' perception of two nonnative consonant contrasts. *Infant Behavior and Development, 18,* 339–350.

Bloom, L. (1973). *One word at a time: The use of single word utterances before syntax.* The Hague, The Netherlands: Mouton.

Brown, C., & Matthews, J. (1997). The role of feature geometry in the development of phonemic contrasts. In S. J. Hannahs & M. Young-Scholten (Eds.), *Focus on phonological acquisition* (pp. 67–112). Amsterdam: Benjamins.

Brown, C. A. (in press). The interrelation between speech perception and phonological acquisition from infant to adult. In J. Archibald (Ed.), *Second language grammars.*Oxford, England: Blackwell.

Casasola, M., & Cohen, L. B. (2000). Infants' association of linguistic labels with causal actions. *Developmental Psychology, 36,* 155–168.

Charles-Luce, J., & Luce, P. A. (1990). Similarity neighbourhoods of words in young children's lexicons. *Journal of Child Language, 17,* 205–215.

Charles-Luce, J., & Luce, P. A. (1995). An examination of similarity neighbourhoods in young children's receptive vocabularies. *Journal of Child Language, 22,* 727–735.

Clark, E. (1973). What's in a word? On the child's acquisition of semantics in his first language. In T. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 65–110). New York: Academic.

Cohen, L. B. (1998). An information-processing approach to infant perception and cognition. In F. Simion & G. Butterworth (Eds.), *The development of sensory, motor and cognitive capacities in early infancy: From perception to cognition* (pp. 277–300). Hove, England: Psychology Press.

Cohen, L. B., & Cashon, C. H. (2001). Infant object segregation implies information integration. *Journal of Experimental Child Psychology, 78,* 75–83.

Diesendruck, G., & Shatz, M. (1997). The effect of perceptual similarity and linguistic input on children's acquisition of object labels. *Journal of Child Language, 24,* 695–717.

Edwards, M. L. (1974). Perception and production in child phonology: The testing of four hypotheses. *Journal of Child Language, 1,* 205–219.

Eilers, R., & Oller, D. K. (1976). The role of speech discriminations in developmental sounds substitutions. *Journal of Child Language, 3,* 319–329.

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thal, D. J., & Pethick, S. J. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development, 59,* 1–173.

Ferguson, C. A., & Farwell, C. B. (1979). Words and sounds in early language acquisition. *Language, 51,* 419–439.

Fernald, A. (1985). Four-month-old infants prefer to listen to motherese. *Infant Behavior and Development, 8,* 181–195.

Fernald, A., McRoberts, G. W., & Herrara, C. (1991, April). *Prosody in early lexical comprehension.* Paper presented at the Society for Research in Child Development, Seattle, WA.

Fernald, A., McRoberts, G. W., & Swingley, D. (in press). Infants' developing competence in recognizing and understanding words in fluent speech. In J. Weissenborn & B. Hoehle (Eds.), *Approaches to bootstrapping in early language acquisition.* Amsterdam: Benjamins.

Fernald, A., Pinto, J. P., Swingley, D., Weinberg, A., & McRoberts, G. W. (1998). Rapid gains in speed of verbal processing by infants in the second year. *Psychological Science, 9,* 228–231.

Friederici, A. D., & Wessels, J. M. I. (1993). Phonotactic knowledge and its use in infant speech perception. *Perception and Psychophysics, 54,* 287–295.

Garnica, O. K. (1973). The development of phonemic speech perception. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 215–222). New York: Academic.

Gerken, L. A., Murphy, W. D., & Aslin, R. N. (1995). Three- and four-year-olds' perceptual confusions for spoken words. *Perception and Psychophysics, 57,* 475–486.

Gogate, L. J., & Bahrick, L. E. (1998). Intersensory redundancy facilitated learning or arbitrary relations between vowel sounds and object in seven-month-old infants. *Journal of Experimental Child Psychology, 69,* 133–149.

Hallé, P., & de Boysson-Bardies, B. (1994). Emergence of an early receptive lexicon: Infants' recognition of words. *Infant Behavior and Development, 17,* 119–129.

Hallé, P., & de Boysson-Bardies, B. (1996). The format of representation of recognized words in infants' early receptive lexicon. *Infant Behavior and Development, 19,* 463–481.

Hoff-Ginsberg, E. (1997). *Language development.* Pacific Grove, CA: Brooks/Cole.

Hoskins, S. S., & Golinkoff, R. M. (under review). Novel minimal pair discrimination in 31–35-month-olds.

Jusczyk, P. W. (1994). Infant speech perception and the development of the mental lexicon. In J. C. Goodman & H. C. Nusbaum (Eds.), *The development of speech perception: The transition from speech sounds to spoken words* (pp. 227–270). Cambridge, MA: MIT Press.

Jusczyk, P. W. (1997). *The discovery of spoken language.* Cambridge, MA: MIT Press.

Jusczyk, P. W. (1999). How infants begin to extract words from speech. *Trends in Cognitive Sciences, 3,* 323–328.

Jusczyk, P. W., & Aslin, R. N. (1995). Infants' detection of sound patterns of words in fluent speech. *Cognitive Psychology, 29,* 1–23.

Jusczyk, P. W., Cutler, A., & Redanz, N. (1993). Preference for predominant stress patterns of English words. *Child Development, 64,* 675–687.

Jusczyk, P. W., Friederici, A. D., Wessels, J. M., Svenkerud, V. Y., & Jusczyk, A. M. (1993). Infants' sensitivity to the sound patterns of native language words. *Journal of Memory and Language, 32,* 402–420.

Karzon, R. G. (1985). Discrimination of polysyllabic sequences by one-to-four-month-old infants. *Perception and Psychophysics, 232,* 105–109.

Kay-Raining Bird, E., & Chapman, R. S. (1998). Partial representations and phonological selectivity in the comprehension of 13- to 16-month-olds. *First Language, 18,* 105–127.

Keating, P. A. (1984). Phonetic and phonological representation of stop consonant voicing. *Language, 60,* 286–319.

Keating, P. A. (1988). Underspecification in phonetics. *Phonology, 5,* 275–292.

Markman, E. M. (1987). How children constrain the possible meanings of words. In U. Neisser (Ed.), *Concepts and conceptual development: Ecological and intellectual factors in categorization* (pp. 225–287). New York: Cambridge University Press.

Markman, E. M. (1989). *Categorization and naming in children: Problems of induction.* Cambridge, MA: MIT Press.

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

Merriman, W. E., & Bowman, L. L. (1989). The mutual exclusivity bias in children's word learning. *Monographs of the Society for Research in Child Development, 54,* 1–123.

Merriman, W. E., & Schuster, J. M. (1991). Young children's disambiguation of object name reference. *Child Development, 62,* 1288–1301.

Metsala, J. L. (1999). Young children's phonological awareness and nonword repetition as a function of vocabulary development. *Journal of Educational Psychology, 16,* 1–27.

Metsala, J. L., & Walley, A. C. (1998). Spoken vocabulary growth and the segmental restructuring of lexical representations: Precursors to phonemic awareness and early reading ability. In J. L. Metsala & L. C. Ehri (Eds.), *Word recognition in beginning literacy* (pp. 89–120). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Mills, D. L., Werker, J. F., Stager, C. L., Prat, C. S., Zangle, R., Applebaum, G., Adamson, A., Sanders, L., Mitchell, T., & Neville, H. (in preparation). *Semantic processing of phonetically similar words in infants: Indications from event-related potentials.*

Morgan, J. L., & Saffran, J. R. (1995). Emerging integration of sequential and suprasegmental information in preverbal speech segmentation. *Child Development, 66,* 911–936.

Myers, J., Jusczyk, P. W., Kemler-Nelson, D. G., Charles-Luce, J., Woodward, A. L., & Hirsch-Pasek, K. (1996). Infants' sensitivity to word boundaries in fluent speech. *Journal of Child Language, 23,* 1–30.

Nelson, K. E., & Bonvillian, J. D. (1973). Concepts and words in the 18-month-old: Acquiring concept names under controlled conditions. *Cognition, 2,* 435–450.

Pater, J., Stager, C., & Werker, J. F. (1998). Additive effects of phonetic distinctions in word learning. In *Proceedings of the 16th International Congress on Acoustics and 135th Meeting of the Acoustical Society of America* (pp. 2049–2050). Norfolk, VA: ASA.

Pater, J., Stager, C., & Werker, J. F. (2001). *Additive effects of phonetic distinctions in word learning.* Manuscript under review.

Pegg, J. E., & Werker, J. F. (1997). Adult and infant perception of two English phones. *Journal of the Acoustical Society of America, 102,* 3742–3753.

Pierrehumbert, J. (1990). Phonological and phonetic representation. *Journal of Phonetics, 18,* 375–394.

Plunkett, K., Bailey, T., & Bryant, P. E. (2000, July). Phonological representation and word recognition. In P. W. Jusczyk (Chair), *Learning to recognize words in fluent speech.* Symposium conducted at the meeting of the International Society on Infant Studies, Brighton, England.

Plunkett, K., Sinha, C., Moller, M. F., & Strandsbury, O. (1992). Symbol grounding or the emergence of symbols? Vocabulary growth in children and a connectionist net. *Connection Science, 4,* 293–312.

Polka, L., & Werker, J. F. (1994). Developmental changes in perception of nonnative vowel contrasts. *Journal of Experimental Psychology: Human Perception and Performance, 202,* 321–435.

Pollock, K. E. (1987). Phonological perception of early words in young children using a visual search paradigm. *Dissertation Abstracts International, 48*(2B), 405.

Prat, C. S., Stager, C. L., Mitchell, T. V., Adamson, A. M., & Sanders, L. D. (1999, April). *Semantic processing of phonetically similar words in infants: Indications from event-related potentials.* Poster presented at the Society for Research in Child Development, Albuquerque, NM.

Rice, K., & Avery, P. (1995). Variability in a deterministic model of language acquisition: A theory of segmental elaboration. In J. Archibald (Ed.), *Phonological acquisition and phonological theory* (pp. 23–42). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Schafer, G., & Mareschal, D. (2001). Modeling infant speech sound discrimination using simple associative networks. *Infancy, 2,* 7–28.

Schafer, G., & Plunkett, K. (1998). Rapid word learning by fifteen-month-olds under tightly controlled conditions. *Child Development, 69,* 309–320.

Shvachkin, N. K. (1973). The development of phonemic speech perception in early childhood. In C. Ferguson & D. Slobin (Eds.), *Studies of child language development* (pp. 91–127). New York: Holt, Rinehart & Winston. (Original work published 1948)

Stager, C. L. (1999). *A study of the phonetic detail used in lexical tasks during infancy.* Unpublished doctoral dissertation, University of British Columbia, Vancouver, Canada.

Stager, C. L., & Werker, J. F. (1997). Infants listen for more phonetic detail in speech perception than in word-learning tasks. *Nature, 388,* 381–382.

Stager, C. L., & Werker, J. F. (1998). Methodological issues in studying the link between speech perception and word learning. In C. Rovée-Collier, L. P. Lipsitt, & H. Hayne (Series Eds.), E. Bavin & D. Burnham (Vol. Eds.), *Advances in infancy research* (pp. 237–256). Stamford, CT: Ablex.

Subrahmanyam, K., Landau, B., & Gelman, R. (1999). Shape, material, and syntax: Interacting forces in children's learning in novel words for objects and substances. *Language and Cognitive Processes, 14,* 249–281.

Swingley, D., & Aslin, R. N. (2000). Spoken word recognition and lexical representation in very young children. *Cognition, 76,* 147–166.

Swingley, D., Pinto, J. P., & Fernald, A. (1999). Continuous processing in word recognition at 24 months. *Cognition, 71,* 73–108.

Taylor, M., & Gelman, S. A. (1988). Adjectives and nouns: Children's strategies for learning new words. *Child Development, 59,* 411–419.

Tomasello, M., Mannle, S., & Werdenschlag, L. (1988). The effect of previously learned words on the child's acquisition of words for similar referents. *Journal of Child Language, 15,* 505–515.

Tsao, F., Liu, H., Kuhl, P. K., & Tseng, C. (2000, July). *Perceptual discrimination of a Mandarin fricative–affricate contrast by English-learning and Mandarin-learning infants.* Poster presented at the meeting of the International Society on Infant Studies, Brighton, England.

Walley, A. C. (1993). The role of vocabulary development in children's spoken word recognition and segmentation ability. *Developmental Review, 13,* 286–350.

Waxman, A., & Senghas, S. R. (1992). Relations among word meanings in early lexical development. *Developmental Psychology, 28,* 862–873.

Werker, J. F., Cohen, L. B., Lloyd, V. L., Casasola, M., & Stager, C. L. (1998). Acquisition of word–object associations by 14-month-old infants. *Developmental Psychology, 34,* 1289–1309.

Werker, J. F., & Lalonde, C. E. (1988). Cross-language speech perception: Initial capabilities and developmental change. *Developmental Psychology, 24,* 672–683.

Werker, J. F., & McLeod, P. (1989). Infant preference for both male and female infant-directed talk: A developmental study of attentional and affective responsiveness. *Canadian Journal of Psychology, 43,* 230–246.

Werker, J. F., & Pegg, J. E. (1992). Infant speech perception and phonological acquisition. In C. A. Ferguson, L. Menn, & C. Stoel-Gammon (Eds.), *Phonological acquisition* (pp. 285–311). Timonium, MD: York Press.

Werker, J. F., & Stager, C. L. (2000). Developmental changes in infant speech perception and early word learning: Is there a link? In M. Broe & J. Pierrehumbert (Eds.), *Papers in laboratory phonology 5* (pp. 181–193). Cambridge, England: Cambridge University Press.

Werker, J. F., & Tees, R. C. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development, 7,* 49–63.

Woodward, A. L., Markman, E. M., & Fitzsimmons, C. M. (1994). Rapid word learing in 13- and 18-month-olds. *Developmental Psychology, 30,* 553–566.