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Infants' Recognition of Vowel Contrasts in a Word Learning Task

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1.0 Introduction

At the end of the first year of life, there is a confluence of two major developments in infant language acquisition. Infants this age are emerging from a period of refining their speech perception skills to native-language contrasts (e.g., Werker & Tees, 1984). Concurrently, the infants' word learning skills are solidifying. Although infants have some success with word learning prior to 12 months of age (Tincoff & Jusczyk, 1999), the second year of life witnesses a veritable explosion of word comprehension and acquisition (e.g., Feldman, et al., 2000). The key question for the current paper is how speech perception cues influence the emergence of word learning, and vice-versa.

1.1. Word learning in infancy

Even very young infants' have a robust ability to remember word forms, where no meaning is attached to sequences of sounds. Newborns can remember a simple word form for over 24 hours (Swain, Zelazo & Clifton, 1993) and 9-month-old infants can retain the sound patterns of frequently presented words for two weeks (Jusczyk & Hohne, 1997). We see the beginnings of true word comprehension in the second half the first year of life, when infants understand the meaning of a few very frequent word forms. Studies using parental reports of children's vocabularies suggest that infants as young as 8 months of age comprehend an average of 36 words (Bates, Dale & Thal, 1995). Yet, laboratory studies provide evidence for limited word understanding in this age range. Few experimental studies provide clear evidence of infants' ability to look correctly toward a referent in the presence of a label (Tincoff & Jusczyk, 1999), and many of these studies indicate only partial success prior to 12-months (see Woodward & Markman, 1998, for a review). Beyond 1 year, however, infants demonstrate comprehension of an increasing number of words in laboratory settings. Beginning around 14 months of age, infants can reliably link words and objects in arbitrary associations, without considerable contextual support, in a lab task (Schafer & Plunkett, 1998; Werker, Cohen, Casasola, Lloyd & Stager, 1998).

1.2. Relating speech perception to early word learning

During the first year of life infants are acquiring a great deal of knowledge about their native language. In particular, they are learning about the relevant sound categories (e.g., Werker & Tees, 1984) and legal sound combinations (Jusczyk, Luce & Charles-Luce, 1994). They are also pulling sequences of sounds and syllables out from the speech stream (e.g., Jusczyk & Aslin, 1995). A key question for word learning is whether or not infants are guided by the native-language knowledge built up during the first year of life. To explore this, Stager and Werker (1997) used a version of the Switch task developed by Werker, et al. (1998) to examine whether infants of 14 months were sensitive to the phonetic detail in newly learned words. In this task, infants are habituated to two object-label combinations (Object A – Word A; Object B – Word B) and are tested on their ability to notice a 'switch' in the pairings (Object A – Word B). Although infants this age could successfully learn to link phonetically dissimilar novel words such as [lIf] and [nim] to two different objects, they failed when the new words were phonetically similar, such as [bI] and [dI]. Importantly, infants can discriminate these syllables in a simple discrimination task, where no objects are involved. To explain these findings, Stager and Werker proposed a "resource limitation" account. Infants of 14 months do not succeed in this task because they are not yet accomplished word learners. The computational demands of learning the words, the objects, and their links interfered with the novice word learners' ability to efficiently use the phonetic detail in the words.

The resource limitation account is supported by the fact that processing load reductions in the task seem to facilitate success in using phonetic detail. Infants who have greater expertise with word learning (i.e., older infants and 14-month-old infants with large vocabularies) succeed at learning the minimally different words [bI] and [dI] in the Switch task (Werker et al., 2002). When the demands of the Switch Task are eased by using minimally different *known* words (e.g., 'ball' [bal] vs. 'doll' [dal]), 14-month-old infants succeed, as there is no need to learn the link in the task (Fennell & Werker 2003; see also Swingley & Aslin, 2002). Reductions in task demands also lead to infant success in using phonetic detail in words (Ballem & Plunkett, 2005; Fennell, 2004).

Given that increased cognitive demands may easily overwhelm novice word learners' ability to use speech detail in novel words, emergent phonemes might become available to the child to direct attention to relevant information (Werker & Curtin, 2005). Werker and Curtin argued that phonemes emerge (likely in a staggered fashion) only after a criterial number of meaningful words are stored in the lexicon. This would explain the success of both older infants and infants with larger vocabularies in learning minimally distinct words. In the absence of phonemes, infants must rely on other information sources to detect differences in minimal pairs, such as general perceptual categories or exemplar word forms. Problems may arise in early word learning when resources are limited and there is nothing available to direct attention to the relevant property of the word-form.

1.3 Limited Focus of Past Research on Consonants

Most research exploring early word-object associative learning has examined infants' ability to detect minimal differences in consonants (Fennell, 2004; Pater, Stager & Werker, 2005; Stager & Werker, 1997; Werker, et al., 2002). These differences are often determined based on phonological feature specifications. For example, the above studies use the following contrasts: /b/ - /d/, differing in place of articulation; /d/ - /g/, also differing in place; /b/ - /p/ , differing in voicing; and /d/ - /p/ differing in both place of articulation and voicing. It is, however, possible to differentiate between sound segments using auditory cues. In this case, /b/ - /d/ and /d/ - /g/ differ in their formant transitions whereas /b/ and /p/ differ in voice onset time (VOT), and /d/ and /p/ differ again in two ways, formant transitions and VOT. Regardless of whether phonological features or auditory cues are used, the segments differ in either one or two features/cues, and 14-month-old infants failed at detecting any of the differences in novel words. Given these consistent null results and the parallel number of differences between segments, it is not possible to determine whether infants can exploit phonological features or auditory cues. We argue that early on infants do not have access to phonemes (and hence phonological features). In the absence of phonology to guide information pickup and ease resources, only salient auditory information will be available. Since the use of consonants has not easily differentiated auditory cues and phonological features, we tested infants' ability to detect minimal vowel differences in novel words in order to determine if auditory cues have primacy in early word learning.

1.4. Using Vowels to Distinguish Phonological and Auditory Cues

Vowels have richer auditory information than consonants: carrying more prosodic information, realized as longer duration and higher amplitude. The rich cues present in vowels may be reflected in developmental speech perception. Infants narrow their perceptual focus to native vowels by 6 months of age (Kuhl et al., 1992; Polka & Werker, 1994), several months before narrowing their perceptual focus to native consonants (Werker & Tees, 1984). Therefore, the first question was whether the earlier refining and increased salience of vowels facilitated their use in early word learning. For this reason, we tested infants younger than those infants who succeeded in earlier work.

Our major question was whether phonological features or auditory cues matter more in early word learning. Unlike consonants, would the salience and richness of vowels allow us to distinguish phonological and auditory cues? To answer these questions, we explored novice word learners' ability to use the /i/-/I/ and /i/-/u/ contrasts in novel words. There are different predictions for these contrasts based on whether infants are weighing phonological features or auditory cues more when learning novel words (see Table 1). The first contrast only differs in one phonological feature, but differs in multiple auditory cues; whereas, the second contrast differs in two phonological features, but only one auditory cue. In general, a contrast with a two feature/cue difference should have a greater chance for success than one with only a single feature/cue difference. Thus, phonological feature weighting would result in infant success only in the /i/-/u/ contrast, and infant reliance on auditory cues would result in success only in the /i/-/I/ contrast. Importantly, research has demonstrated that infants successfully discriminate both contrasts in speech perception tasks (Swomboda, Morses & Leavitt, 1976; Polka & Bohn, 1996; Polka & Werker, 1994).

Table 1: Phonological Features versus Auditory Cues

Contrast	**Phonological Differences**	**Auditory Cue Differences**	**Prediction: Ability to Distinguish Words**	
			Phonological	Auditory
/i/ vs. /I/	Height	F1; F2; duration[1]	No	Yes
/i/ vs. /u/	Frontness; Roundness	F2[2]	Yes	No

2.0 Experiment 1

This experiment was designed to test the hypothesis that vowel detail is accessed in a word learning task at an earlier age (13-months) than consonant detail (17 months). The target words differed in the /i/ - /I/ contrast, allowing us to begin testing whether infants rely more on auditory than phonological cues, as described above. The use of this vowel contrast is comparable to the earlier work with consonants as it differs only by a single *phonological* feature: height[3].

2.1 Method

2.1.1. Participants

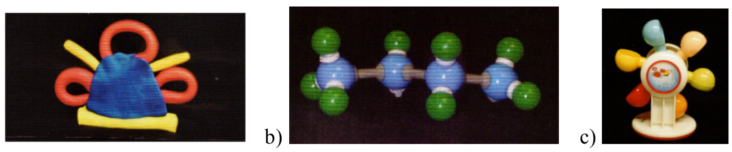
Thirty-two 13-month-old infants completed the study: 16 males and 16 females. Their mean age was 13 months, 13 days (12 m, 28 d – 14m, 3d). All infants in Experiments 1, 2, and 3 were exposed primarily to Canadian English (at least 80% exposure) and had no apparent or reported health problems.

2.1.2. Stimuli

We recorded a female native speaker of Canadian English producing two

1. In our stimuli duration is equated across contrasts. See Table 4 for details.
2. /u/ is a rounded vowel and so there is some lowering of the higher formants in addition to the change in F2.
3. Depending on the feature system one might argue that the difference is one of + or - ATR (advanced tongue root) or one between tense and lax vowels. Regardless, there is a single feature difference that defines this contrast.

CVC non-words using infant-directed speech. The same speaker was used in all subsequent experiments. The non-words minimally differed only in the vowel: "deet" (/dit/) and "dit" (/dIt). Each novel word was paired with a novel object. One object was fashioned out of red, yellow, and blue clay (see Figure 1a). The other was a blue and green molecule model (see Figure 1b). A store-bought, multicoloured toy water wheel ("spinner") was used for both the pre- and post-tests (see Figure 1c). The same visual stimuli were used in all Experiments.



a) b) c)

Figure 1: Visual stimuli for all Experiments

2.1.3. Apparatus

Testing took place in an 2.8 m by 2.3 m quiet room, dimly lit by a shaded 60W lamp situated 80 cm to the left of the infant at a 45 degree forward angle. The infant sat on the parent's lap facing a 27-inch Mitsubishi CS-27205C video monitor approximately 1.2 m away. The audio stimuli were delivered at 65 dB, +/- 5 dB, over a BOSE 101 speaker, located directly above the monitor. Black cloth stretching the width and height of the room surrounded the monitor. Infants were recorded using a Sony DCR-TRV11 digital video camera with the lens peeking out of a 6.4 cm hole in the black cloth located 21 cm below the monitor. As a masking control, the parent wore Koss TD/65 headphones over which female vocal music played from a Sony CFD-V17 CD player. The Habit 2000 program (Cohen, Atkinson, & Chaput, 2000) was used to order stimuli presentation and collect looking time data and was run on a Macintosh Power PC G4. The visual and audio stimuli played from digitized files on the computer and were sent to the monitor and speaker in the testing room. The experimenter, blind to the audio stimuli and to trial type (habituation or test), 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 Habit 2000 recorded. The video record was used for subsequent reliability coding. The same apparatus was used in Experiment 2.

2.1.4. Design

On the pre-test trial, the infant heard the label "neem" paired with the spinner object. Infants were then habituated to two word-object pairings and tested on their ability to detect a switch, or mismatch, in the pairing. The infant, seated on a parent's lap, viewed a moving object on the monitor, which was accompanied by an auditory label. The word-object pairings repeated until the infant's looking time declined to a criterial level (65%) across a block of four trials, indicating infant habituation. Following the habituation phase, the test phase began, which determined whether the infant learned not only about the words and objects individually, but also linked Object A to Word A and Object B to Word B. This involved two test trials. In the control trial (the 'Same' trial), a word and an object were presented in a familiar combination (e.g., Object A - Word A). In the test trial (the 'Switch' trial), a word and an object from habituation were presented, but the pairing was violated (e.g., Object A - Word B). If the infant learned about the words and the objects, but did not learn the associative link, the 'Same' and 'Switch' trials would be equally familiar, resulting in equal looking times. If the infant learned the link between the specific words and objects, she should look longer to the 'Switch' than to the 'Same' trial. In a post-test trial, the infant was again presented with the spinner-"neem" pairing. If the infant was still involved in the task, her looking time should recover from habituation. We used the same design in all Experiments.

2.2 Results

Paired t-tests confirmed that infants recovered to the post-test from the last habituation block in this and all subsequent studies ($p < .001$). The main set of analyses addressed infants' performance at test. A 2 (sex: female vs. male) X 2 (test trials: same vs. switch) mixed ANOVA revealed no significant main effects or interactions (all $p > .05$). Counter to our prediction, infants did not look significantly longer on switch ($M = 6.91$ s) than on same ($M = 5.94$ s) trials. (See Figure 2.) However, a follow-up analysis showed a looking time by test order interaction. A 2 (test trial order: same before switch vs. switch before same) X 2 (test trials: same vs. switch) mixed ANOVA revealed a significant interaction between test trial order and test trials [F (1, 30) = 5.16, $p = .03$]. Infants who received the Switch trial ($M = 7.5$s) following the Same trial ($M = 4.85$ s) succeeded at detecting a mismatch in the pairing, whereas those infants who received the Switch trial ($M = 6.32$ s) before the Same trial ($M = 7.04$ s) failed to distinguish the minimally different words at test (See Figure 2).

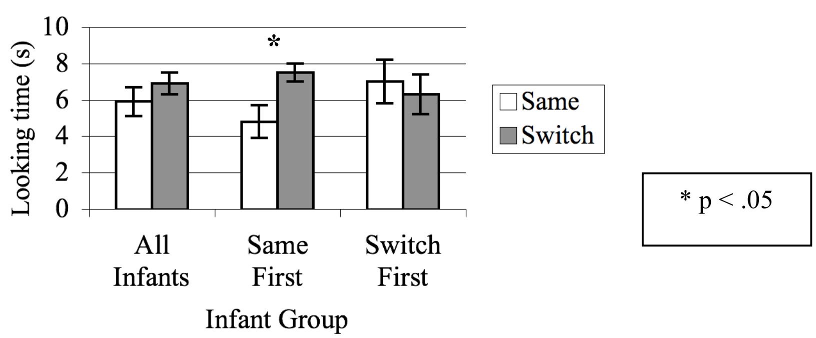


Figure 2. Mean looking times for Same and Switch trials in Experiment 1.

2.3. Discussion

The order effect indicates that 13-month-old infants have a tenuous ability to use vowel detail in new word forms. Infants who experienced Switch before Same may have noticed the violation, but their surprise at the change may have carryied over to the subsequent Same test trial, resulting in high looking times to the both trials. This possibility would indicate that novice word learners took advantage of the multiple acoustic cues present in the novel words. However, the infants may have been able to exploit the one phonological feature present, unlike their failures to use phonological features with consonants. We needed to obtain clearer results in order to explore this issue.

3.0 Experiment 2

Based on the tenuous results from Experiment 1, we tested slightly older infants in the same procedure and predicted that the effect seen in the one testing order of Experiment 1 would generalize across orders. Infants in this experiment were still younger (15-months) than the age at which consonant detail is first noticed in this task (17-months.)

3.1 Methods

3.1.1 Participants

Sixteen 15-month-old infants participated in this study: 8 males and 8 females. Their mean age was 15 months, 17 days (15 m, 6 d – 16 m, 1 d).

3.2 Results

A 2 (sex: female vs. male) X 2 (test trials: same vs. switch) mixed ANOVA revealed a significant main effect for test trial [$F(1, 14) = 4.72$, $p = .047$]. Infants looked significantly longer to the Switch ($M = 10.85$ s) than to the Same ($M = 7.25$ s) trials. (See Figure 3.)

3.3. Discussion

The 15-month-old infants' longer looking time to Switch demonstrates that they are able to use the single phonological feature and/or the two auditory cues present in the vowels. Thus, as predicted, novice word learners can use vowel detail in word learning prior to consonant detail. But, will the vowel success extend over different contrasts, like the consonant failures? Moreover, although infants' success is consistent with the prediction that auditory cues are weighted more than phonological features, we were unable to determine whether or not infants are successfully using the phonological feature or the auditory cues. Experiment 3 addressed this by increasing the number of phonological features to two, while simultaneously minimizing the auditory cue differences to one.

4.0 Experiment 3

To test whether 15-month-old infants are primarily using phonological features or auditory cues, we examined their ability to distinguish two words differing in the /i/ - /u/ contrast. The phonological distance between /i/ and /u/ is quite large compared to /i/ and /I/ (See Table 3). Thus, the phonological position would predict that since infants succeed with the /i/ - /I/ contrast, they should also succeed with the /i/ - /u/ contrast. However, the auditory cue prediction would be that infants will not succeed at detecting a switch in the pairing. The auditory cues – specifically F1 and F2 – suggest that these vowels are actually quite similar. Acoustic measurements for our stimuli, which were equated for duration, show that there is a large difference in both F1 and F2 for the /i/ - /I/ contrast, but only a difference in F2 for the /i/ - /u/ contrast (See Table 4). Thus, unlike the /i/ - /I/ contrast from the previous experiments, where there was a close phonological distance but two auditory cues, the /i/ - /u/ contrast has a greater phonological distance but only one auditory cue (See Table 1).

Table 3. Phonological Space for Vowels

	front	central	back
high **Semi-high**	i ɪ	ɨ	u ʊ
mid **Mid-low**	e ɛ	ə	o ɔ
low	æ	a	ɑ

Table 4. Measurements for stimuli used in these studies.

Auditory Cue	/I/	/i/	/u/
F1 (Hz)	570	395	406
F2 (Hz)	2148	2638	1793
Duration (ms)	540	540	520

4.1 Methods
4.1.1. Participants

Twenty 15-month-old infants participated in this study: 10 males and 10 females. Their mean age was 15 months, 10 days (14 m, 15 d – 16m, 4 d). Six additional infants did not habituate and were excluded from the analyses.

4.1.2. Stimuli

All video stimuli and the pre-/post-test audio stimuli were identical to

Experiments 1 and 2. The habituation audio stimuli were two CVC non-words minimally differing in the /i/-/u/ vowel contrast: “deet” (/dit/) and “doot” (/dut/).

4.1.3. Apparatus

Testing for Experiment 3 took place at a different location from Experiment 1 and 2. Only the differences between locations will be highlighted below. Testing took place in a 2.74 m by 1.82 m quiet room, dimly lit by overhead lighting. The infant sat on the parent’s lap facing a Smartboard monitor (122 cm wide x 91.5 cm high) mounted on the wall that was approximately 1.5 m away. Images are projected onto the Smartboard via a NEC LT245 projector. The audio stimuli were delivered at 65 dB, +/- 5 dB, over a BOSE 101 speaker, located directly below the monitor. The infants were recorded using a Sony DCRDVD92 digital video camera. The lens of the digital video camera peeked out of an opening in a neutral coloured cloth located 45 cm below the monitor. As a masking control, the parent wore Bose True Noise-cancellation headphones over which vocal music was played from a Teac CD-P1250 CD player. Habit X 1.0 (Cohen, Atkinson, & Chaput, 2004) was used to order stimuli presentation and collect looking time data and was run on a Macintosh Power PC G5.

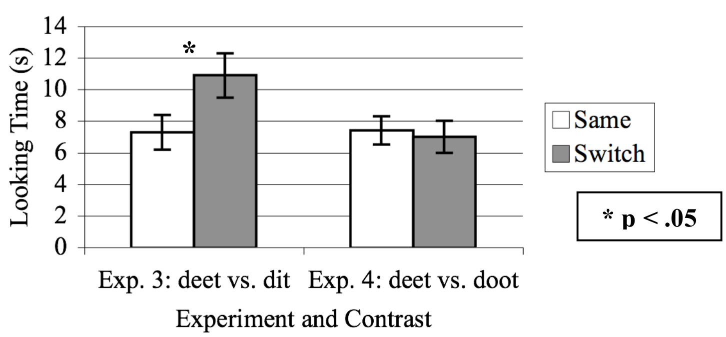


Figure 3. Mean Looking Times for Same and Switch Trials.

4.2 Results

A 2 (sex: female vs. male) X 2 (test trials: same vs. switch) mixed ANOVA revealed no significant main effects or interactions (all $p > .05$). Counter to the phonological prediction, infants did not look significantly longer on switch ($M = 6.98$ s) than on same ($M = 7.42$ s) trials. (See Figure 3.)

4.3. Discussion

The 15-month-olds are not detecting a Switch (i.e., looked equally long at both test trials). Unlike the 13-month-olds who did not detect a change in the word-object pairing for the /i/ - /I/ contrast, there was no effect of test trial order ($p > .05$). This suggests that infants have no tenuous ability to detect mismatches in word-object associations with this particular contrast.

5.0 General Discussion

Unlike consonants, vowels can be distinguished before 17 months of age. However, this is not the case for all vowel contrasts. The auditory approach predicts which vowels distinctions can be used for early word learning, whereas phonological categories do not resolve the question (see Table 5).

Table 5. Summary of Vowel Contrasts

			Ability to Distinguish Words		
Contrast	**Phonological Features (PF)**	**Auditory Cues (AC)**	**Prediction**		**Actual Results**
			PF	AC	
/i/ vs. /I/	Height	F1; F2	No	Yes	Yes
/i/ vs. /u/	Frontness; Roundness	F2	Yes	No	No

Infants do not seem to have adult-like phonological categories (i.e. phonemes). Rather, they rely on reliable auditory differences along individual continua (i.e. F1, F2, etc). This is compatible with the proposals of two models of infant perceptual/lexical development, viz. PRIMIR (Werker & Curtin 2005) and Linguistic Perception (LP) (Escudero, 2005). The two approaches are distinct in that PRIMIR would argue that it is not possible to refer to cues in terms of the number required to define a contrast. Rather, PRIMIR would suggest that there is category formation at the general perceptual level akin to warping of perceptual space based on cue weighting and co-occurrences. The LP, on the other hand, would argue that changes in perception initially results from constraints which map the signal onto auditory-phonetic categories (Boersma, Escudero, & Hayes, 2003). Currently, this study does not address which approach best characterizes the word learning situation.

The emergence of vowel phonemes is supported by a study examining older word learners use of a phonological feature in word learning. Dietrich, Swingley and Werker (2004) studied 18-month-old infants' use of vowel duration in distinguishing a novel minimal pair. Importantly, they used two infant groups: a Dutch-learning group for whom vowel duration is phonological and an English-learning group for whom vowel duration serves no phonological purpose. Only the Dutch-learning infants successfully distinguished the novel words. These results demonstrate that, as predicted by PRIMIR and LP, that phonological features emerge over time and become weighted more than auditory cues.

However, another study with older word learners produced results that seem to contrast with our findings and those of Dietrich et al. (2004). Using an interactive object categorization task, Nazzi (2005) tested infants' ability to use vowel and consonant information in the objects' labels. He found that 20-month-old infants had greater success in using consonant information than in using vowel information. The infants confused labels that minimally differed in their vowel, but succeeded in distinguishing labels that minimally differed in consonant information. Nazzi attributed older word learning infants' failure to use vowel information as a result of their greater focus on consonants in word learning (Nespor, Peña, & Mehler, 2003). It may be that Nazzi's object categorization task placed different demands on the infants than the object-label associative task used in both our study and Dietrich et al.'s work. Infants may have relaxed their tolerance for vowel differences when dealing with a real speaker and multiple labels. On the other hand, infants in our task hear only one speaker producing the words and the words are heard repeatedly during habituation. Vowel differences, once developmentally available, may be highlighted in attention due to this design. Further research using both tasks is needed to determine the developmental trajectory of vowel use over infancy.

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