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Phonological specificity of vowels and consonants in early lexical representations

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Abstract

Infants become selectively sensitive to phonological distinctions relevant to their native language at an early age. One might expect that infants bring some of this phonological knowledge to bear in encoding the words they subsequently acquire. In line with this expectation, studies have found that 14-month-olds are sensitive to mispronunciations of initial consonants of familiar words when asked to identify a referent. However, there is very little research investigating infants' sensitivity to vowels in lexical representations. Experiment 1 examines whether infants at 15, 18 and 24 months are sensitive to mispronunciations of vowels in familiar words. The results provide evidence for vowels constraining lexical recognition of familiar words. Experiment 2 compares 15, 18 and 24-month-olds' sensitivity to consonant and vowel mispronunciations of familiar words in order to assess the relative contribution of vowels and consonants in constraining lexical recognition. Our results suggest a symmetry in infants' sensitivity to vowel and consonant mispronunciations early in the second year of life.

Keywords: Phonological specificity; Vowels; Consonants; Lexical representation

Introduction

New-born infants are precocious in their ability to discriminate phonetic contrasts not present in their native language (Eimas, Siqueland, Jusczyk, & Vigoriti, 1971; Kuhl, 1987). However, infants are no longer able to discriminate non-native phonetic contrasts at the end of their first year of life (Werker & Tees, 1984; Werker & Lalonde, 1988). Since infants also begin to produce and understand words around this age, it has been argued that this loss of language-universal phonetic discrimination is caused by the association of sounds with meaning (Werker & Tees, 1984). Nevertheless Kuhl, Williams, Lacerda, Stevens, and Lindblom (1992) report that infants display greater sensitivity to native than to non-native vowels by 6 months—well before an understanding of word meaning has developed. Indeed, recent research by Maye, Werker, and Gerken (2002) finds that exposure to the distribution of the speech sounds in the infants' native language has an extremely influential role in driving this preference for native language speech sounds—suggesting a less crucial role for the introduction of word-object associations. A part of the infant's phonological repertoire appears to be in place before lexical acquisition is set in motion. Consequently, this phonological repertoire

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might actually facilitate early lexical development, by providing the means to discriminate words.

Previous studies have shown that infants' lexical representations are at least partially phonologically specified. These studies report that infants look longer at a target object when its label is correctly pronounced than when the label is mispronounced, even when the mispronunciation involves a single featural change. A mispronunciation effect has been reported for word-initial consonants in familiar words as early as 14 months (Bailey & Plunkett, 2002; Ballem & Plunkett, 2005; Swingley & Aslin, 2000, 2002) and word-medial consonants at 19 months (Swingley, 2003). This suggests that infants do not appear to encode words vaguely. A possible interpretation of this finding is that infants' phonological representations are similar to adult representations of familiar words—fully specified in phonetic detail. Although this adult-oriented perspective requires further confirmation of infant sensitivity across a full range of consonantal feature changes, it is noteworthy that the majority of previous studies have only tested infants' sensitivity to mispronunciations of *consonants* in lexical recognition or word-learning tasks (Bailey & Plunkett, 2002; Ballem & Plunkett, 2005; Fennell & Werker, 2003; Stager & Werker, 1997). The role of vowels in infant's recognition of familiar words has not been similarly explored. The only studies to include vowel mispronunciations were Swingley and Aslin (2000, 2002). These studies analysed 14-month-old (Swingley & Aslin, 2002) and 18- to 23-month-old infants' (Swingley & Aslin, 2000) sensitivity to mispronunciations of six words, two of which were vowel mispronunciations, while the rest were consonant mispronunciations. Infants were presented with two pictures for 3 s, after which one of the images was named in the carrier phrase 'Where's the [target]?' Swingley and Aslin report that infants at both age groups took longer to switch from the distracter to the target when the target label was mispronounced than when it was correctly pronounced. However, a significant bias towards the target image remained even following mispronunciations. This effect was also significant by items, suggesting that there were no differences between infants' sensitivity to vowel and consonant mispronunciations.

Swingley and Aslin do not provide a systematic analysis of infants' sensitivity to vowel mispronunciations *alone*. Of the two words that were mispronounced by the vowel—*apple* (mispronounced as *opple*) and *car* (mispronounced as *cur*)—one involved a word-initial vowel mispronunciation in a bisyllabic word, and the other a word-final vowel mispronunciation in a monosyllabic word. Conversely, all consonant mispronunciations were word-initial in monosyllabic words alone. While this does not invalidate the overall mispronunciation effect reported in both studies (Swingley & Aslin, 2002), their results do not provide a general test of infant sensitivity to vowel mispronunciations given that only two words were mispronounced in an identical fashion for all infants and the locus of the mispronunciation differed in each word. A more stringent test of infant vowel sensitivity in lexical processing needs to examine a greater range of vowels and words, where the location of the mispronunciation is carefully controlled.

There are good reasons to suppose that vocalic identity might play a central role in lexical recognition: vowels carry the major acoustic energy associated with speech, being longer and louder than consonants and provide important cues to prosodic structure. Infants' sensitivity to vowels in their native language is acquired much earlier than similar sensitivity to language-specific consonants (Kuhl et al., 1992). Bond (1954) argues that vowel changes to words are more likely to lead to lowered comprehensibility than consonant changes in adults. Finally, Gerken, Murphy, and Aslin (1995) found that pre-schoolers were more sensitive to vowel changes in bisyllabic words than consonant changes, though no differences were found for monosyllabic words. These findings indicate a prominent role for vowels and consonants in lexical recognition and suggest that vowel mispronunciations in familiar words would have a similar effect on infant responding as consonant mispronunciations.

In addition, some studies suggest that production of most vowels is mastered early, with full mastery over consonants only appearing later (Templin, 1957). The longer duration of vowels compared to consonants may make them easier for infants to articulate, based on infants' general preference for longer sounds in production (Smith, 1978). Until recently, not many production studies had focussed on infants' age of acquisition of vowels, because vowels were considered to be mastered much earlier than consonants and tended to be accurately articulated. More recently, however, some studies have found that infants accurately produce a number of consonants and vowels at around the same age—by about 15 months of age, infants appear to have mastered /b, d g, n, h, w/ in their consonant inventory (Robb & Bleile, 1994) and /i, u, o, ɑ, ʌ/ in their vowel inventory (Selby, Robb, & Gilbert, 2000; Stoel-Gammon & Herrington, 1990). Further analysis suggests that infants have acquired both rounded and unrounded, front and back, and high and low vowels in their vowel inventory. However, infants do not master any voiceless stops or most fricatives until 18–36 months of age. We lack evidence suggesting that infants' mastery of production of a particular segment affects their perception of mispronunciations of this segment. However, if perception sensitivities were to reflect production abilities, we might expect to observe a heightened sensitivity to vowel mispronunciations compared to consonant mispronunciations in early lexical recognition.

An alternative perspective based on typological analysis is 'that the task of distinguishing lexical items rests more on consonants than on vowels' (Nespor, Pena, & Mehler, 2003, p. 209). These authors argue that consonants are specialised for conveying information about the lexicon whereas vowels provide information about prosody and grammar. Previous studies report that adults are more likely to replace vowels than consonants in tasks involving changes from non-words to words (Cutler, Sebastian-Galles, Soler-Vilageliu, & van Ooijen, 2000; Van Ooijen, 1996). In addition, vowels are perceived less categorically than consonants, suggesting some variability in the perception of vowels (Liberman, Delattre, Cooper, & Gerstman, 1954; Pisoni, 1973) and the acoustic characteristics of vowels are also very susceptible to inter-speaker differences in production (Peterson & Barney, 1952). From this perspective, one might expect infants to show less sensitivity to mispronunciations of vowels than consonants when recognising the referent of a familiar word.

A study by Nazzi (2005) offers some support for the view that consonants play a more central role in lexical acquisition than vowels. Using a name-based categorisation task (Nazzi & Gopnik, 2001), Nazzi reports that 20-month-old French infants can learn simultaneously two novel words that differ by either the word-initial or non-initial consonants while being unable to learn two words that differ by their vowels. This result supports Nespor et al.'s (2003) claim that the task of distinguishing lexical items rests more on consonants than on vowels. It is also noteworthy in this context, that Caramazza, Chialant, Capasso, and Micell (2000) found a double dissociation between the processing of vowels and consonants in aphasic patients, and argued that this demonstrated categorically distinct representations of vowels and consonants that could not be reduced to a featural level.

Overall, the evidence for the phonological specificity of vowels in early lexical representations is equivocal. The studies by Swingley and Aslin (2000, 2002) suggest a degree of phonological specificity of vowels in familiar words as early as 14-months-old. However, this finding is based on infant responses to just two words (and consequently mispronunciations of just two vowels). Hence, the generality of the finding must be questioned. In contrast, Nazzi's (2005) study suggests that infants fail to discriminate vowels in a lexical acquisition task whereas they do discriminate between consonants. Both the nature of the tasks (named-based categorisation vs. mispronunciation) and the status of the lexical items (novel vs. familiar) differ in these studies, so direct comparison is not straightforward. Nevertheless, the implications of the studies are divergent and therefore require empirical clarification.

We describe two sets of experiments designed to evaluate infant sensitivity to vowel identity in early lexical representations. In the first set of experiments, we use a mispronunciation task to evaluate the generality of Swingley and Aslin's finding that infants are sensitive to vowel identity in familiar words. In line with Swingley and Aslin, we predict that infants will be sensitive to vowel mispronunciations. In a second set of experiments, we compare infant sensitivity to vowel and consonant mispronunciations in familiar words. On the basis of Nespor et al.'s claims and Nazzi's findings, one might predict that infants will be more sensitive to consonant mispronunciations than vowel mispronunciations of familiar words.

Experiment 1

The first series of experiments in this study examines whether infants at 15, 18 and 24 months are sensitive to mispronunciations involving changes in the word-medial vowels of familiar monosyllabic words. Using the intermodal preferential looking task (for details see Bailey & Plunkett, 2002; Ballem & Plunkett, 2005), infants are presented with correct and incorrect labels for familiar objects. If infants have phonologically detailed lexical representations including information about vowel identity, then infants should look longer at a target object when the label is correctly pronounced than when it is incorrectly pronounced. Such a finding would provide support for the hypothesis that vowels play a prominent role during word recognition in the early developing lexicon. If infants fail to show sensitivity to vowel mispronunciations of familiar words, the hypothesis that vowels are not central to constraining lexical identity in the early lexicon would be supported.

Method

Participants

The participants in this experiment were 28 infants at 15 months ($M = 15.04$ months; range = 14.1–15.4 months; 13 M and 15 F), 30 infants at 18 months ($M = 18.1$ months; range = 17.3–18.6 months; 17 M and 13 F) and 31 infants at 24 months ($M = 24.28$ months; range = 23.7–25.1 months; 16 M and 15 F). Thirteen additional infants were tested but were excluded due to fussiness, parental interference, or experimenter error (8 at 15 months; 2 at 18 months; 3 at 24 months). All infants had no known hearing or visual problems and were recruited via the maternity ward at the John Radcliffe Hospital in Oxford. Infants came from homes where British English was the only language in use. All parents were asked to complete the Oxford Communicative Developmental Inventory (OCDI; Hamilton, Plunkett, & Schafer, 2000), a British adaptation of the MacArthur CDI (Fenson et al., 1993).

Stimuli

The stimuli presented to infants at 18 and 24 months were 16 monosyllabic (CVC) nouns taken from the OCDI. Each infant heard eight labels, half of which were correctly pronounced while the other half were incorrectly pronounced. Following Ballem and Plunkett (2005), mispronunciations were created by changing one or more of the dimensions of the vowel (i.e., height, backness, roundedness), usually resulting in a non-word. There were two exceptions (*dog* → *dig* and *doll* → *dill*) involving mispronunciations that resulted in real words that were judged unknown to the infants according to OCDI reports. In four words, mispronunciations involved changes to one of the dimensions of the vowel alone—backness (1) or height (3). In all other cases, mispronunciations involved large changes to at least two dimensions of the vowel—backness, roundedness, or height (see Table 1 for details). Table 1 gives a complete listing of the words and their corresponding mispronunciations.

The speech stimuli were produced by a female speaker of British English in an enthusiastic, child-directed manner. The audio recordings were made with a digital audio tape recorder (DAT) in a sound-attenuated, recording booth. The audio stimuli were then digitised at a sampling rate of 44.1 kHz and a resolution of 16 bits. Each of the auditory stimuli was then spliced into the carrier phrase "Look! *target word*!" using Goldwave 5.10. The duration, fundamental frequency, and intensity of the correctly pronounced and mispronounced labels are given in Table 1. There was no systematic difference in the duration ($t(15) = -1.489$; $p = .15$), fundamental frequency ($t(15) = -.008$, $p = .99$) and intensity ($t(15) = .831$, $p = .419$) of the correct and mispronounced labels.

Infants at 15 months were tested on a slightly different set of 10 monosyllabic (CVC) words. The change in testing materials was necessitated by the smaller vocabularies of the younger infants. The changes involved reducing the number of test stimuli and adding two new words (see Table 2). Again, the audio stimuli were spoken by a female speaker of British English in an enthusiastic voice. The durations, fundamental frequency, and intensity of the correctly pronounced and mispronounced labels presented to infants at 15 months are given in Table 2. Two of the mispronunciations involved changes in only one of the vowel dimensions—backness (1) or height (1). All the other mispronunciations involved large changes of two vocalic dimensions—backness, roundedness, or height (see Table 2 for details). There was no systematic difference in the duration ($t(9) = .944$, $p = .37$), fundamental frequency ($t(9) = -.516$, $p = .618$) or intensity ($t(9) = .874$, $p = .405$) of the correct and mispronounced labels.

Visual stimuli were computer images created from photographs, with one image for each word. Images were judged by three adults (the authors and an independent observer) as typical exemplars of the labelled category.

Procedure

During the experiment, all infants sat on their caregiver's lap approximately 80 cm away from a projection screen (1.3 m × .35 m). Two cameras mounted directly above the visual stimuli recorded infants' eye-movements. Synchronised signals from the two cameras were then routed via a digital splitter to create a recording of

Table 1
Durations of the correctly pronounced and mispronounced labels presented to infants at 18 and 24 months (Experiment 1)

Correct pronunciation	Dur (ms)	f_0 (Hz)	Amp (dB)	Incorrect pronunciation	Dur (ms)	f_0 (Hz)	Amp (dB)	Main dimension changes			Distracter
								Back	Round	Height	
Ball	577	307	83	Bal /bæl/	543	334	83	–	–		Bed
Bed	537	338	82	Bod /bɔd/	528	339	81	+	+		Ball
Bib	503	356	80	Bab /bæb/	565	351	82			–	Boot
Book	528	351	80	Bik /bɪk/	557	356	78	–	–		Bus
Boot	616	342	77	Bot /bɔt/	680	332	81			–	Bib
Bread	593	341	80	Brod /brɔd/	600	348	83	+	+		Brush
Brush	703	315	82	Brish /brɪʃ/	715	338	78	–		+	Bread
Bus	652	334	81	Bis /bɪs/	613	323	78	–		+	Book
Dish	655	358	79	Dush /dƱʃ/	644	316	81	+	+		Doll
Dog	524	338	83	Dig /dɪg/	517	357	78	–	–	+	Duck
Doll	520	299	83	Dill /dɪl/	599	312	81	–	–	+	Dish
Duck	560	393	80	Dack /dæk/	559	375	82	–			Dog
Milk	667	343	79	Marlk /mɑlk/	724	336	80	+		–	Moon
Moon	721	309	81	Marn /mɑn/	675	297	81		–	–	Milk
Sock	704	376	81	Souk /sƱk/	728	314	78			+	Sun
Sun	659	288	81	Sen /sɛn/	704	361	78	–		+	Sock
Mean	607	336	80	Mean	621	336	80				

Table 2
Durations of the correctly pronounced and mispronounced labels presented to infants at 15 months (Experiment 1)

Correct pronunciation	Dur (ms)	f_0 (Hz)	Amp (dB)	Incorrect pronunciation	Dur (ms)	f_0 (Hz)	Amp (dB)	Main dimension changes			Distracter
								Back	Round	Height	
Ball	627	254	79	Bal /bæl/	597	201	77	–	–		Bed
Bed	573	302	80	Bod /bɔd/	568	266	77	+	+		Ball
Bib	569	260	80	Bab /bæb/	563	264	80			–	Book
Book	617	306	80	Bik /bɪk/	510	367	77	–	–		Bib
Bread	670	275	79	Brod /brɔd/	685	258	82	+	+		Brush
Brush	729	273	77	Brish /brɪʃ/	696	269	79	–		+	Bread
Cup	667	400	78	Kip /kɪp/	778	381	77	–		+	Keys
Dog	578	308	77	Dig /dɪg/	542	328	78	–	–	+	Duck
Duck	647	244	79	Dack /dæk/	602	316	76	–			Dog
Keys	729	283	78	Koos /ku:z/	700	322	78	+	+		Cup
Mean	640	290	78	Mean	624	297	78				

two separate time-locked images of the infant. Caregivers wore headphones throughout the experiment and were instructed to keep their eyes shut.

Infants at 18 and 24 months were each presented with eight trials. In each trial, infants saw images of two familiar objects, side-by-side, for 5 s. The distance between images was 15 cm. One of the objects was then named in the carrier phrase "Look! *target word*!" with either a correct label or a mispronunciation. The auditory signal was delivered through a centrally located loudspeaker situated immediately above the projection screen. Onset of the target word began halfway into the trial at 2500 ms. This onset divided the trial into a pre- and post-naming phase. Infants saw each object only once during the experiment paired with another distracter object whose label began with the same onset consonant. The requirement that target and distracter have labels with the same onset consonant ensures that infants cannot use the label onset to identify the target referent (Fernald, Swingley, & Pinto, 2001). Infants must therefore pay attention to the vowel nucleus for successful target identification. The target–distracter pairings are listed in Table 1. Across infants, images appeared as target or distracter with equal frequency. Likewise, words were equally likely to be correctly pronounced and mispronounced. Half of the labels presented to infants were correctly pronounced while the other half were incorrectly pronounced. Infants never heard the same object labelled with both an incorrect and a correct pronunciation. Targets appeared equally often to the left and to the right. Likewise, correct and incorrectly pronounced words identified left and right targets equally often. Order of presentation of trials was randomised across infants.

The current study presents infants with just eight trials, compared to the Swingley and Aslin (2000, 2002) studies which presented infants with 24 test trials. The relatively small number of trials is motivated by the requirement that both target and distracter have names that begin with the same onset consonant (see above) and an attempt to avoid any priming effects due to repetition of stimuli, thus ensuring that infants were not presented with the same picture twice in the same experiment and that they did not hear both correct and incorrect pronunciations of the same word. While the number of trials could have been increased by adding bisyllabic words or vowel-initial words, the current study attempted to localise the source of any mispronunciation effects: infants were only presented with word-medial vowel mispronunciations of closed, monosyllabic words. Infants' sensitivity to mispronunciations in different word positions and mispronunciations of bisyllabic words have yet to be systematically explored.

Fifteen-month-old infants know fewer words and hence it is even more difficult to find pairs of objects whose names begin with the same onset consonant. Fifteen-months-olds were presented with 10 trials, each trial having the same overall form as that presented to the older infants. The trials were divided into two testing blocks where infants saw each pair of objects once in each block, i.e., infants were presented with five pairs of images twice. For each pair, one of the objects was labelled in one of the blocks while the other object was labelled in the other block. Hence, the second block of testing permitted evaluation of vowel sensitivity to a greater range of words for every infant. If the label of one of the objects of a pair was correctly pronounced in the first block, the label for the other object of the pair was mispronounced in the second block and vice versa. Therefore, an object in a pair was never the target object in both blocks. This ensured that infants did not hear correct and incorrect pronunciations of the same word in the experiment. Half of the labels were correctly pronounced and the other half were incorrectly pronounced and each image appeared equally often as target and distracter. Across infants, words were equally likely to be correctly pronounced and mispronounced. Half of the infants heard 3 mispronunciations and 2 correct pronunciations in the first block and 2 mispronunciations and 3 correct pronunciations in the second block. For the other half of the infants, this was reversed. Order of presentation of the trials was randomised within a block and image pairs were counterbalanced for target-side and mispronunciations.

Scoring

A digital-video scoring system was used to assess visual events on a frame-by-frame basis (every 40 ms). This technique enabled tracking of every eye fixation. A second skilled coder evaluated the data from 10% of the participants. Coders achieved a high level of agreement ($r = .95$, $p < .001$).

The coded video frames were used to determine the amount of time infants' looked at the target (*T*) and distracter (*D*) images in the two phases of each trial; before and after the onset of the target word. Similarly, we also calculated the length of infants' longest fixations at the target (*t*) and distracter (*d*) for the two phases of each trial. As in previous research, it was assumed that the amount of time required by infants to initiate an eye-movement was 367 ms (Swingley & Aslin, 2000, 2002; Swingley, Pinto, & Fernald,1999). Consequently, analysis of the post-naming phase of the trial was initiated 367 ms after the onset of the target word. This ensures that the analyses only consider changes in infants' looking behaviour that can reasonably constitute a response to the spoken word. In addition, only those trials in which infants fixated both the target *and* the distracter during the pre-naming phase of the trial were included. For the 15-month-old infants, we relaxed this criterion slightly to require only that they fixated both pictures sometime during the entire course of the trial. This was necessary because the 15-month-olds made fewer saccades during the course of stimulus presentation than the older infants. On the basis of these criteria, we excluded 31 trials (14 trials at 15 months; 14 trials at 18 months; 3 trials at 24 months) from the analysis.

We calculated the difference ($t - d$) between infants' longest look (LLK) at target (*t*) and distracter (*d*) images before and after target word onset (Bailey & Plunkett, 2002; Ballem & Plunkett, 2005; Meints, Plunkett, & Harris, 1999; Schafer & Plunkett, 1998). A difference measure is used to calculate the target preference during each phase of the trial because the longest looks involve only single fixations on target and distracter. Systematic increments in infants' longest look at the target across the two phases of the trial can be interpreted as a measure of the child's understanding of the target word (Bailey & Plunkett, 2002; Meints et al., 1999; Reznick, 1990; Schafer & Plunkett, 1998; Swingley & Aslin, 2000).

We also calculated the amount of time infants spent looking at the target (*T*) over the amount of time infants' spent looking at the target and distracter ($T + D$) in order to determine the proportion of time infants spent looking at the target—proportion of target looking measure (PTL). As with the LLK measure, a significant increase in infants' preference for the target across the two phases of the trial indicates infants' association of the target label and target object.

Results of the main ANOVAs using the LLK and PTL measure will be reported in tables. However, planned comparisons will mainly be reported using the LLK measure. Planned comparisons using the PTL measure will only be reported if there are differences in the results between the two measures. Previous studies have found that the LLK measure provides a more sensitive index of infants' comprehension (Meints et al., 1999; Schafer & Plunkett, 1998; Southgate & Meints, 1999). Schafer and Plunkett argue that the PTL measure is more susceptible to decreasing infant participation during the course of the trial. As the trial proceeds, infants may become distracted and start to display looking patterns not necessarily related to the auditory stimulus—one might reasonably expect gaze switches farther from the time of presentation of auditory stimulus to be less related to the occurrence of the auditory stimulus. The PTL measure may, therefore, provide a more general measure of the level of infant interest in the target object aroused upon presentation of an auditory stimulus. The LLK measure, on the other hand, may provide a more direct measure of the time it takes the infant to check that the label matches the object.

Some studies also report the amount of time taken by infants to switch from the distracter image to the target image upon hearing the target label as an index of infants' preference for the target image (Fernald et al., 2001; Swingley & Aslin, 2000, 2002; Swingley et al., 1999), arguing that longer latencies reflect the extra time required to identify a semantic mismatch (Swingley & Aslin, 2000, pp. 151–2). Since it is usually assumed in these studies that the minimum amount of time required by infants to initiate an eye-movement is around the order of 367 ms, only eye-movements 367 ms after the onset of the target word were considered. A rapid change in gaze after this point is taken as a measure of infants' detection of a mismatch between the picture currently fixated and the target label.

Results

15 months

Fig. 1 plots the difference between the 15-month-olds' preference for the target in the pre- and the post-naming phases of Block 1 and Block 2 using the LLK measure. Fig. 1 suggests that there was no systematic difference in infants' preference for the target

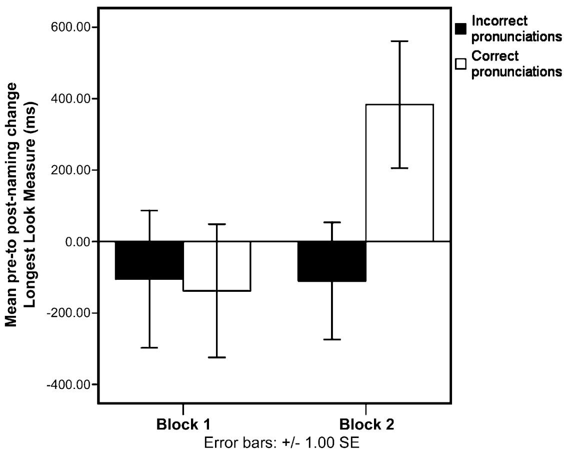

Fig. 1. Experiment 1: mean difference between the pre- and post-naming phase of the correctly pronounced and mispronounced trials in Blocks 1 and 2 presented to 15-month-olds (Longest look data).

between the pre- and the post-naming phase when the target label was mispronounced. Conversely, there was an increase in preference for the target from the pre- and the post-naming phase when the target label was correctly pronounced in Block 2.

The results of a 3×2 repeated-measures ANOVA with the factors naming (pre- and post-naming), accuracy of pronunciation (correct and incorrect) and block are reported in Table 3 by subjects and by items for both measures. The associated min F' values are also reported in Table 3. A significant main effect of block (by subjects) and a significant interaction between naming and pronunciation (by items) indicated that there was a systematic difference in infants' looking behaviour in the two blocks and that there was a significant difference in infants' looking behaviour following correct and incorrect pronunciations. The data from the two blocks were analysed separately.

Block 1. The results of a 2×2 repeated-measures ANOVA using only the factors naming and accuracy of pronunciation on the data from the first block are also reported in Table 3. These results indicate that infants failed to respond systematically to correct or incorrect pronunciations of the target label during the first block of testing.

Block 2. The results of a 2×2 repeated-measures ANOVA using the factors naming and pronunciation on the data from Block 2 are also reported in Table 3. The significant interaction between naming and pronunciation found in the ANOVA indicates systematic differences in infants' looking behaviour between the pre- and post-naming phases in the correctly pronounced and mispronounced conditions. The means and confidence intervals of the increment in target looking for the different pronunciation conditions are reported below.

Planned comparisons using the LLK measure revealed that there was a significant difference in infants' preference for the target from the pre- to the post-naming phase following correct pronunciations ($M = 383$ ms (CI: 18, 748)). The difference was near-significant using the PTL measure. Conversely, there was no significant difference in infants' preference for the target from the pre- to the post-naming phase following incorrect pronunciations using either measure (LLK: $M = -95$ ms (CI: $-229, 421$)).

Latency analysis of Block 2. Analysis of the response latencies in Block 2 yielded similar results. Infants were fixating the distracter picture at the disambiguation point (367 ms after onset of target word) in 42.4% of the trials. Of these trials, infants switched from the distracter to the target image 84.2% of the time, thereby providing response latencies on 35.5% of all trials ($.42 \times .84$). Swingley and Aslin (2002) argue that younger infants are less likely to provide reliable latency measures. Consequently, latency measures for the young infants in the Swingley and Aslin study were analysed using unaggregated data. Using the same method of analysis, the 15-month-olds in the current study took an average of 617 ms to switch from the distracter to the target image upon hearing correct pronunciations of the target label. Conversely, infants took an average of 966 ms to switch from the distracter to the target image upon hearing incorrect pronunciations of the target label. Infants exhibited delayed response times to mispronunciations compared to correct pronunciations of the target label, suggesting that infants were sensitive to mispronunciations of the target label. A one-way ANOVA indicated that the difference between conditions was significant (($F(1, 47) = 5.809$; $p = .02$); mean difference = 349 ms (CI: 57, 641)).

These results indicate that infants at 15 months are sensitive to mispronunciations of familiar words when the mispronunciations involve a change to the vocalic nucleus. However, this sensitivity was only observed during the second block of testing.

18 and 24 months

Since the 18- and 24-month-olds were presented with the same experiment, the data from both age groups was analysed together. Fig. 2 plots the difference between infants' preference for the target in the pre- and the post-naming phase using the LLK measure. Fig. 2 suggests that there was no systematic difference in infants' preference for the target between the pre- and the post-naming phase when the target label was mispronounced. Conversely, there was an increase in preference for the target between the pre- and the post-naming

Table 3
Analysis of variance results for Experiment 1 (15-month-olds) (significant effects are highlighted in bold)

Effect	Block	*F*1 (subject analysis)						*F*2 (item analysis)						Min *F*′	
		PTL			LLK			PTL			LLK			PTL	LLK
		F	*df*	*p*	*F*	*df*	*p*	*F*	*df*	*p*	*F*	*df*	*p*		
Naming	1 and 2	.092	1,27	.763	.005	1,27	.944	.990	1,9	.346	.208	1,9	.660	$F(1,31) = .084$	$F(1,28) = .004$
Pronunciation	1 and 2	.921	1,27	.346	.486	1,27	.492	**5.177**	**1,9**	**.049**	2.075	1,9	.184	$F(1,34) = .781$	$F(1,35) = .393$
Block	1 and 2	**5.390**	**1,27**	**.028**	3.690	1,27	.065	4.342	1,9	.067	**7.518**	**1,9**	**.023**	$F(1,24) = 2.432$	$F(1,35) = 2.475$
*N * P*	1 and 2	2.320	1,27	.139	2.155	1,27	.154	**9.837**	**1,9**	**.012**	**6.271**	**1,9**	**.034**	$F(1,35) = 1.877$	$F(1,36) = 1.603$
*N * B*	1 and 2	.203	1,27	.656	1.563	1,27	.222	.994	1,9	.345	**6.058**	**1,9**	**.036**	$F(1,35) = .168$	$F(1,36) = 1.242$
*P * B*	1 and 2	1.732	1,27	.199	**5.024**	**1,27**	**.033**	2.850	1,9	.126	4.503	1,9	.063	$F(1,35) = 1.077$	$F(1,26) = 2.374$
*N * P * B*	1 and 2	2.033	1,27	.165	3.347	1,27	.078	1.900	1,9	.201	2.083	1,9	.183	$F(1,26) = .982$	$F(1,21) = 1.283$
Naming	1	.027	1,28	.871	.626	1,28	.435	.017	1,9	.899	1.004	1,9	.343	$F(1,21) = .010$	$F(1,33) = .385$
Pronunciation	1	.024	1,28	.877	.348	1,28	.560	.213	1,9	.656	.494	1,9	.500	$F(1,32) = .021$	$F(1,32) = .204$
*N * P*	1	.002	1,28	.966	.022	1,28	.883	.013	1,9	.911	.272	1,9	.615	$F(1,35) = .001$	$F(1,32) = .020$
Naming	2	.336	1,28	.567	.911	1,28	.348	3.784	1,9	.084	**5.140**	**1,9**	**.050**	$F(1,32) = .308$	$F(1,35) = .773$
Pronunciation	2	2.721	1,28	.111	3.318	1,28	.080	3.083	1,9	.113	**5.324**	**1,9**	**.046**	$F(1,29) = 1.445$	$F(1,33) = 2.044$
*N * P*	2	**4.229**	**1,28**	**.050**	**6.905**	**1,28**	**.014**	3.397	1,9	.098	4.468	1,9	.064	$F(1,24) = 1.883$	$F(1,22) = 2.712$

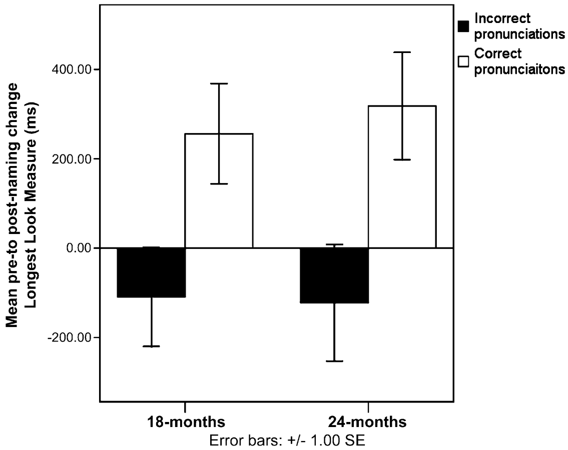

Fig. 2. Experiment 1: mean difference between the pre- and post-naming phase of the correctly pronounced and mispronounced trials presented to 18- and 24-month-olds (longest look data).

phase when the target label was correctly pronounced. The data were analysed using a mixed model ANOVA with the factors naming (pre- and post-naming) and pronunciation accuracy (correct and mispronounced) as within-subjects factors and age (18 and 24 months) as a between-subjects factor (see Table 4 for results of analysis by subjects and by items, together with associated min F' values—significant F_1, F_2 and min F' values are in bold).

The significant interaction between naming and pronunciation indicates systematic differences in infants' looking behaviour between the pre- and post-naming phase in the correctly pronounced and mispronounced conditions. Importantly, there was no main effect of age or any significant interactions with age. The means and confidence intervals of the increment in target looking for the different pronunciation conditions are reported below, separated by age using the LLK measure.

18 months. There was a significant difference in infants' preference for the target from the pre- to the post-naming phase following correct pronunciations ($M = 256$ ms (CI: 26, 485)). Conversely, there was no significant difference in infants' preference for the target from the pre- to the post-naming phase following incorrect pronunciations ($M = -109$ ms (CI: $-336, 117$)).

24 months. The results with the 24-month-olds were similar to the 18-month-old infants. There was a significant difference in infants' preference for the target from the pre- to the post-naming phase following correct pronunciations ($M = 318$ ms (CI: 73, 563)). Conversely, there was no significant difference in infants' preference

Table 4
Analysis of variance results for Experiment 1 (18- and 24-month-olds) (significant effects are highlighted in bold)

Effect	*F*1 (subject analysis)						*F*2 (item analysis)						Min *F*′	
	PTL			LLK			PTL			LLK			PTL	LLK
	F	*df*	*p*	*F*	*df*	*p*	*F*	*df*	*p*	*F*	*df*	*p*		
Naming	2.663	1,59	.108	2.276	1,59	.137	2.226	1,30	.146	1.661	1,30	.146	$F(1,75) = 1.212$	$F(1,71) = .960$
Pronunciation	.478	1,59	.492	2.154	1,59	.148	.742	1,30	.396	2.509	1,30	.396	$F(1,88) = .290$	$F(1,83) = 1.158$
Age	.007	1,59	.932	.008	1,59	.929	.001	1,30	.933	.000	1,30	.933	$F(1,39) = .000$	$F(1,59) = .007$
$N*A$	.071	1,59	.790	.047	1,59	.830	.206	1,30	.653	.106	1,30	.653	$F(1,36) = .052$	$F(1,89) = .032$
$P*A$	.361	1,59	.550	.206	1,59	.652	.713	1,30	.405	.248	1,30	.405	$F(1,89) = .239$	$F(1,84) = .112$
$N*P$	**11.205**	**1,59**	**.001**	**10.578**	**1,59**	**.002**	**8.285**	**1,30**	**.007**	**9.766**	**1,30**	**.007**	**$F(1,71) = 4.763$**	**$F(1,77) = 5.077$**
$N*P*A$	.034	1,59	.854	.091	1,59	.764	1.234	1,30	.276	.084	1,30	.276	$F(1,62) = .033$	$F(1,77) = .043$

for the target from the pre- to the post-naming phase following incorrect pronunciations ($M = -122$ ms (CI: $-388, 143$)).

For both measures, and at both age-groups, correct pronunciations resulted in systematic increments in looking from the pre- to the post-naming phase of the trial, whereas mispronunciations did not. These results indicate that infants at 18 and 24 months of age were sensitive to mispronunciations of the vowels in familiar words.

Latency analysis

Analysis of the response latencies yielded similar results to the LLK and PTL measures. Infants fixated the distracter picture at the disambiguation point (367 ms after onset of the target word) in 50.5% of trials. Of these trials, infants switched from the distracter to the target image 80.3% of the time. Consequently, response latencies were measured on 40.6% of all trials ($.50 \times .80$). Twenty infants did not provide latency measures in both pronunciations conditions and were excluded from the analysis. The data from the remaining infants showed that infants took an average of 633 ms to switch from the distracter to the target image upon hearing correct pronunciations of the target label. Conversely, infants took an average of 792 ms to switch from the distracter to the target image upon hearing incorrect pronunciations of the target label. The data were analysed using a mixed model ANOVA with pronunciation condition (correct and mispronounced) as a within-subjects factor and age as a between subjects factor (18 and 24 months). There was a significant effect of pronunciation ($F(1,40) = 4.779$, $p = .035$; mean difference = 158 (CI: 14, 302)). The interaction between age and pronunciation was not significant ($F(1,40) = .03$, $p = .86$).

These results indicate that infants switch faster from the distracter to the target when the target label is correctly pronounced compared to when it is mispronounced and, therefore, that infants are sensitive to mispronunciations involving changes to the vowels of familiar words at 18 and 24 months. In addition, there were no systematic differences in the performance of the 18- and 24-month-olds with both age groups showing similar sensitivity to mispronunciations.

Effects of vocabulary size

We calculated the mean receptive percentile vocabulary size of the different age-groups based on parental OCDI reports (*15 months*: $M = 22.2\%$; $SD = 13.5\%$; range: 3–61%; *18 and 24 months*: $M = 58.7\%$; $SD = 24.8\%$; range: 14–99%). Earlier studies have found no evidence of a relationship between vocabulary size and infants' sensitivity to mispronunciations (Bailey & Plunkett, 2002; Ballem & Plunkett, 2005; Swingley & Aslin, 2000, 2002). We measured the correlation between infants' vocabulary size and their sensitivity to mispronunciations, as measured by the difference in naming effect between correct and mispronounced labels. There was no evidence for any correlation at 15 months ($r = -.059$; $p > .5$) or with the older infants ($r = -1.7$, $p > .2$).

We also calculated the mean productive percentile vocabulary size of the different age-groups based on parental OCDI reports (*15 months*: $M = 2.4\%$ words; $SD = 2.1\%$; range: 0–8%; *18 and 24 months*: $M = 34.7\%$; $SD = 27.8\%$; range: 0–94%). We measured the correlation between infants' productive vocabulary size and their sensitivity to mispronunciations, as above. There was no evidence for any correlation at 15 months ($r = -.282$; $p > .1$), or with the older infants ($r = -.11$; $p > .3$). Hence, we find no evidence for a relationship between the phonological specificity of infants' lexical representations and the size of infants' productive or receptive vocabulary (as measured by the OCDI), thereby confirming the findings of earlier studies.

Note that we did not check to see whether infants' ability to produce the words presented to them in the experiment influenced their sensitivity to the mispronunciations. This was for two reasons. First, CDI data cannot tell us whether infants were accurately producing the word, if they were able to say them at all. Second, we cannot assume that there is a deterministic influence between infants' ability to say a word and infants' sensitivity to a mispronunciation of that word. Infants may be able to produce a word accurately but fail to show a mispronunciation sensitivity (or vice versa). Our data do not speak to the otherwise interesting issue of the relationship between perception and production mechanisms.

Discussion

The primary goal of this study was to determine whether infants would recognise that a familiar word was mispronounced when the locus of the mispronunciation was the *vowel* nucleus. Although a considerable body of research has accumulated regarding infant sensitivity to mispronunciations of *consonants* in familiar and novel words, there are no studies that have systematically explored infant sensitivity to vowel changes for familiar word recognition in the second year of life. Our results provide clear evidence that infants are sensitive to mispronunciations of the vowels in familiar monosyllabic words when the word is used to identify a referent. Infants looked significantly longer at a target object in the post-naming phase than in the pre-naming phase of a trial when the labels were correctly pronounced. Conversely, they did not look significantly longer at a target object in the post-naming phase than in the pre-naming phase when the labels were mispronounced. Likewise, infants were faster to switch from the distracter to the target image on hearing correct pronunciations compared to mispronunciations. All the age groups tested in the study showed this sensitivity to vowel mispronunciations, indicating that changes to the vocalic nucleus of familiar labels systematically affected identification of target objects, perhaps as young as 15-months-old, and certainly as young as 18-months-old. This suggests that infant lexical representations contain sufficient phonological information regarding the vowels in familiar words to recognise a mispronunciation of the vowel when identifying a target referent: early lexical representations are not phonologically underspecified, at least for the vowels of the closed, monosyllabic, familiar words tested in this study.

The performance of the 15-month-olds might be interpreted as indicating that the phonological representations for vowels are less robustly specified than for the older infants: while infants displayed sensitivity to mispronunciations of familiar words in the second block of testing, there was no evidence of infants recognising even the correctly pronounced words in the first block. This finding contrasts with Ballem and Plunkett (2005) who found that 14-month-old infants displayed sensitivity to consonant mispronunciations of familiar words even in the first block of testing. This provides an interesting contrast to the results obtained with the 15-month-olds in the current experiment where sensitivity to mispronunciations was found in only the second block of testing, after infants had already been exposed to the object pairs in Block 1.

This might suggest that infants at 15 months only display sensitivity to mispronunciations of vowels upon repetition of object pairs. Does this differ from the pattern of infant sensitivity to consonant mispronunciations found in earlier studies? Note that although infants in the Ballem and Plunkett study showed sensitivity to consonant mispronunciations in Block 1, they had been presented with the same object pairs four times in the first block—twice with correct pronunciations and twice with mispronunciations. Consequently, the consonant mispronunciation effect displayed in Block 1 in Ballem and Plunkett (2005) might have been facilitated by the repeated presentation of object pairs.[1]

A similar pattern is found upon closer analysis of the Swingley and Aslin (2000, 2002) design. Infants in these experiments were also presented with each object pair four times. In the absence of any other data on infants' sensitivity to mispronunciations of consonants following the first presentation of the picture pairs in these studies,

[1] Note that we cannot directly compare the performance of infants in the Ballem and Plunkett design and the current study due to the differences between the two experiments, such as the presentation of training blocks prior to testing blocks, and the presentation of novel objects during training and testing which may have sensitised infants to the mispronunciations.

it is difficult to reach a firm conclusion regarding the dependence of a consonant mispronunciation effect on repetition of picture pairs.

Overall, the results of the current study support the expectations raised by the Swingley and Aslin studies (2000, 2002) that infants will also show sensitivity to vowel mispronunciations in familiar words. The current study goes further in that it provides a systematic exploration of infants' sensitivity to vowel mispronunciations across a much wider range of words, in the absence of confounding factors such as syllabicity of the word being tested, and change in position of the vowel mispronunciation (Swingley & Aslin, 2000, 2002). However, due to the differences between earlier experiments reporting infants' sensitivity to consonant mispronunciations and the current study, any difference in infants' performance between these experiments cannot reliably be attributed to a putative asymmetry between vowels and consonants in infants' lexical representations. Closer consideration of the design of earlier experiments reporting a consonant mispronunciation effect suggests that the latter may be influenced by the repetition of the picture pairs. In order to provide a more direct comparison of the role of consonants and vowels during lexical processing by infants, Experiment 2 tests infants' sensitivity to consonant and vowel mispronunciations of the same words in the same experiment. In addition, Experiment 1 tested infants' sensitivity to mispronunciations of different degrees (along one-dimension and along many-dimensions). Analysis of infants' sensitivity to the different degrees of mispronunciations suggested that none of the age-groups tested were sensitive to one-dimension changes to the vowels (see Appendix). However, the absence of a significant result may have been caused by the small number of infants who contributed to the analysis. Consequently, in Experiment 2, we compare infants' sensitivity to single-dimension changes to the vowels and consonants in order to provide a more appropriate test of infants' sensitivity to small mispronunciations of familiar words.

Experiment 2

Although Experiment 1 provides confirmatory support for the hypothesis that vowels play a prominent role during word recognition, we cannot reject the hypothesis that vowels are *less* central in constraining lexical identity than consonants. Nazzi (2005) presents the only systematic comparison of the differences in effects of consonants and vowels on early word-learning. He found that 20-month-old French infants were unable to learn two words which differed only in their vowels, while being able to learn two words differing in either word-initial or word-medial consonants. He argued that this provides evidence that consonants are more crucial to lexical acquisition than vowels. The striking difference between the ability of the English infants in Experiment 1 to recognise vowel changes in familiar words and the failure of French infants to learn two words which formed a minimal pair on the vowel in the Nazzi (2005) study raises questions about the relative importance of vowels and consonants in lexical access in English infants.

Experiment 2 tests infants' sensitivity to mispronunciations of the vowels and consonants in familiar words in order to provide a systematic comparison of the phonological specificity of vowels and consonants in early lexical representations. In this task, infants were presented with correct and incorrect labels for familiar objects. Unlike Experiment 1, half of the mispronunciations involved word-medial, vowel changes of the familiar CVC labels whereas the other half involved word-initial, consonant changes. If Nazzi's conclusions regarding the relative importance of vowels and consonants in guiding lexical acquisition also relate to lexical access, infants should show greater sensitivity to consonant mispronunciations than to vowel mispronunciations. On the other hand, if vowels and consonants similarly constrain lexical access, there should be no difference in infants' sensitivity to vowel and consonant mispronunciations. Furthermore, Experiment 2 examines infant sensitivity to a change to only one-dimension of the vowels and consonants of the familiar words, thereby providing a more stringent test of the phonological specificity of the underlying lexical representations.

Method

Participants

The participants in this experiment were 29 infants at 15 months ($M = 14.72$ months; range = 13.6–15.6 months, 11 M and 18 F), 27 infants at 18 months ($M = 18.1$ months; range = 17.7–18.8 months, 12 M and 15 F) and 28 infants at 24 months ($M = 23.84$; range = 23.0–24.7, 15 M and 13 F). Twenty additional infants were tested but were excluded due to experimenter error (2), were outliers from the normal population (5), only looked at one picture in each trial (3) or because they did not complete the experiment (10). All infants were recruited according to the same criteria as Experiment 1. Again, all parents were asked to complete the OCDI.

Stimuli

The stimuli presented to infants were eight monosyllabic (CVC) nouns taken from the OCDI. Each infant heard eight labels, half of which were correctly pronounced while the other half were incorrectly pronounced. Each infant heard two vowel mispronunciations, and two consonant mispronunciations. Although it is difficult to ensure equality in the perceived similarity or phonological equivalence of consonant and vowels changes, we attempted to ensure that the changes caused were roughly equivalent by manipulating only one-dimension of either consonant or vowel characteristics. Indeed, previous research has found that the degree of correlation between adult ratings of perceived similarity of phonemes and phonemic feature similarity measures supports the use of the latter in psycholinguistic testing (Bailey & Hahn, 2005, p. 356).

Note also that the stimuli tested make it easier for infants to display sensitivity to consonant mispronunciation than to vowel mispronunciations, since all of the consonant mispronunciations were word-initial, while all vowel mispronunciations were word-medial. Previous research has demonstrated that the word-initial position is extremely salient to infants, with the word onset being adequate to guide infants' recognition of the target object (Fernald et al., 2001). If infants display sensitivity to vowel mispronunciations despite the position of these mispronunciations being less salient compared to the position of the consonant mispronunciations, then this would provide evidence for clear sensitivity to vowel mispronunciations at an early age. Mispronunciations were created by changing one of the dimensions of the vowel (height or backness) or of the consonant (place or voice) and usually resulted in a non-word. There were six exceptions (*cat* → *cart; bed* → *bud; bus* → *bass; bus* → *pus; ball* → *gall; dog* → *bog*) involving mispronunciations that resulted in real words that were judged unknown to the infants according to OCDI reports. Across infants, words were equally likely to receive consonant mispronunciations and vowel mispronunciations. Table 5 gives a complete listing of the words and their corresponding mispronunciations and distracter pairs.

The speech stimuli were produced by a female speaker of British English in an enthusiastic, child-directed manner. The duration, fundamental frequency, and intensity of the correctly pronounced and mispronounced labels are given in Table 5. There was no systematic difference in the overall duration ($F(2,21) = .54$, $p = .58$), intensity ($F(2,21) = 1.569$, $p = .23$) or fundamental frequency ($F(2,21) = .37$, $p = .69$) of the stimuli in the three pronunciation conditions.

Visual stimuli were computer images created from photographs, with one image for each word. As in Experiment 1, images were judged by three adults (the authors and an independent observer) as typical exemplars of the labelled category.

Procedure

The 18 and 24-month-olds were presented with eight trials each. The timing of presentation of the auditory and visual stimuli was identical to that of Experiment 1. Unlike Experiment 1, distracter objects were never labelled due to experimental constraints on the stimuli: first, the labels for the target and distracter objects always began with the same consonant. Second, mispronunciations were always one-dimension mispronunciations of the target label. Together, these constraints made it difficult to find words that permitted one-dimension vowel mispronunciations that did not sound similar to words already known to infants.

In addition, the 15-month-old infants were provided with two wake-up trials before the main experiment in order to familiarise them with the task. Although Experiment 2 had no block design, we hoped to encourage infant participation in the early trials of the experiment through the inclusion of these wake-up trials. The trials were identical to trials in the main experiment, except that there were no mispronunciation trials. The pairs of words presented to infants in the wake-up trials were *fish-sock* and *shoe-bird*. Targets appeared equally often to the left and to the right in the wake-up trials and the main experiment. Likewise, correct and incorrectly pronounced words identified left and right targets equally often. Order of presentation of trials was randomised across infants.

Table 5
Durations of the correctly pronounced and mispronounced labels presented to infants (Experiment 2)

Correct pronunciation	Dur (ms)	f_0 (Hz)	Amp (dB)	Vowel mispronunciation	Dur (ms)	f_0 (Hz)	Amp (dB)	Consonant mispronunciation	Dur (ms)	f_0 (Hz)	Amp (dB)	Distracter
Ball	621	255	80	Bule /bu:l/	706	236	78	Gall	558	265	78	Bear
Bib	440	307	77	Bab /bæb/	517	278	84	Dib	573	294	78	Boot
Bed	563	324	82	Bud /bʌd/	484	280	84	Ped	455	297	82	Book
Bus	596	364	84	Bas /bæs/	635	307	83	Pus	536	314	82	Bike
Cat	557	353	81	Cart /cɑ:t/	618	290	84	Gat	564	346	78	Cow
Cup	575	425	81	Cep /kɛp/	453	408	79	Gup	522	418	83	Car
Dog	532	295	83	Doog /dʊg/	602	274	84	Bog	455	288	83	Duck
Keys	789	268	76	Kas /kæz/	644	336	82	Tees	687	263	76	Coat
Mean	584	323	80	Mean	582	301	82	Mean	543	310	80	

Scoring

The same digital-video scoring system as Experiment 1 was used to analyse infant eye fixations. The coded video frames were used to calculate the LLK and PTL measures of looking behaviour. Only trials where infants fixated both pictures during the entire course of the trial were included in the analysis.

As in Experiment 1, main ANOVAs are reported in tables (see Table 6) using both the PTL and LLK measure. Planned comparisons using the PTL measure will be reported only if they differ from the pattern of the main dependent variable. Note that the use of latency measures to compare consonant and vowel mispronunciations is inappropriate in this experiment as the locus of the mispronunciations types occurs at different time points in the word (consonant onset vs. vowel nucleus). Hence, latency measures in this experiment will only be used to compare consonant mispronunciations with correct pronunciations, and vowel mispronunciations with correct pronunciations. In contrast, the LLK and PTL measures provide a global measure of preference over the complete duration of each phase of the trial.

Results

Fig. 3 plots the difference between infants' preference for the target in the pre- and the post-naming phase for the three pronunciation conditions (correct, vowel and consonant mispronunciation) using the LLK measure at 15, 18 and 24 months of age. Fig. 3 suggests that there was no difference in infants' preference for the target between the pre- and the post-naming phase when the target label was mispronounced, irrespective of whether the mispronunciation changed the vowel or the consonant of the target label. Conversely, there was a systematic increase in preference for the target between the pre- and the post-naming phase when the target label was correctly pronounced. Since the youngest infants were presented with a slightly different version of the experiment (i.e., including two wake-up trials prior to the main experiment), the data from these infants was initially analysed separately.

15 months

The results of the ANOVA with the factors naming (pre- and post-naming) and pronunciation accuracy (correct pronunciations; vowel mispronunciations; and consonant mispronunciations) are presented in Table 6 (reported by items and by subjects, including associated min F' values—significant results are highlighted in bold, while near-significant results are in italics). The interaction between naming and pronunciation in the main ANOVA suggests systematic differences in infants' looking behaviour between the pre- and post-naming phases in the three pronunciation conditions. This

Table 6
Analysis of variance results for Experiment 2 (all age-groups) (significant effects are highlighted in bold)

Effect	*F1* (subject analysis)						*F2* (item analysis)						Min *F'*	
	PTL			LLK			PTL			LLK			PTL	LLK
	F	*df*	*p*	*F*	*df*	*p*	*F*	*df*	*p*	*F*	*df*	*p*		
15-month-olds														
Naming	.040	1,28	.843	.679	1,28	.417	.006	1,7	.942	.176	1,7	.688	$F(1,9) = .005$	$F(1,11) = .139$
Pronunciation	.264	2,27	.770	.118	2,27	.889	.177	2,6	.842	.659	2,6	.551	$F(2,15) = .105$	$F(2,33) = .100$
*N * P*	**4.272**	**2,27**	**.024**	*2.959*	*2,27*	*.069*	**7.684**	**2,6**	**.022**	2.758	2,6	.141	*$F(2,27) = 2.745$*	$F(2,19) = 1.427$
18- and 24-month-olds														
Naming	.088	1,53	.768	.682	1,53	.413	.389	1,13	.54	3.638	1,13	.079	$F(1,66) = .07$	$F(1,64) = .574$
Pronunciation	.863	2,52	.428	1.122	2,52	.333	3.015	2,12	.087	**5.599**	**2,12**	**.019**	$F(2,63) = .670$	$F(92,64) = .934$
Age	.012	1,53	.914	.158	1,53	.693	.004	1,13	.953	.000	1,13	.994	$F(1,22) = .003$	$F(1,65) = .136$
*N * A*	.016	1,53	.900	1.120	1,53	.295	.016	1,13	.90	.014	1,13	.908	$F(1,42) = .008$	$F(91,13) = .013$
*P * A*	.225	2,52	.800	.349	2,52	.707	.341	2,12	.71	.292	2,12	.752	$F(2,50) = .135$	$F(2,43) = .158$
*N * P*	**7.843**	**2,52**	**.001**	**6.514**	**2,52**	**.003**	**4.598**	**2,12**	**.033**	**4.351**	**2,12**	**.038**	*$F(2,28) = 2.89$*	*$F(2,30) = 2.608$*
*N * P * A*	.501	2,52	.609	.697	2,52	.502	.452	2,12	.647	.336	2,12	.721	$F(2,37) = .237$	$F(2,40) = .354$

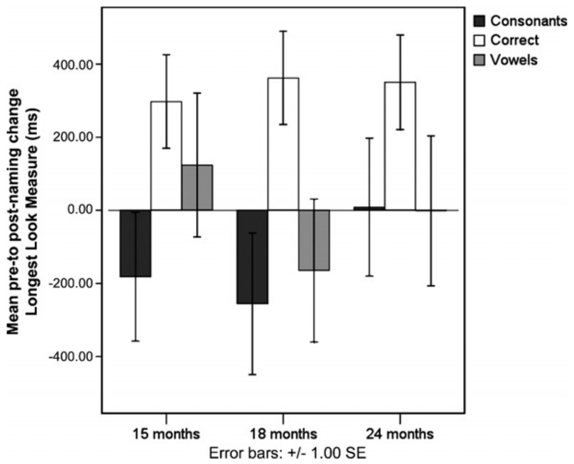

Fig. 3. Experiment 2: mean difference between the pre- and post-naming phase of the correctly pronounced and mispronounced trials (vowel and consonant mispronunciations) presented to 15-, 18- and 24-month-olds (longest look data).

interaction was significant using the PTL measure and marginally significant using the LLK measure.

Planned comparisons revealed that correct pronunciations resulted in systematic increments in looking from the pre- to the post-naming phase of the trial ($M = 297$ (CI: 34, 560)). Conversely, neither consonant ($M = -181$ (CI: −542, 178)) nor vowel mispronunciations ($M = 123$ (CI: −279, 526)) resulted in significant increments in looking from the pre- to the post-naming phase of the trial. We also compared the mean difference in the increment from the pre- to the post-naming phase between the correctly pronounced and the two incorrectly pronounced conditions. There was a significant difference in the increment from the pre- to the post-naming phase between correct pronunciations and consonant mispronunciations ($M = 479$ (CI: 75, 883)). However, the difference in the increment from the pre- to the post-naming phase between correct pronunciations and vowel mispronunciations was not significant ($M = 173$, (−721, 373)). Finally, the difference in the increment from the pre- to the post-naming phase between vowel and consonant mispronunciations was also not significant ($M = 305$, (−211, 822)).

Latency analysis of the data from the 15-month-olds was not possible. There was an insufficient number of trials where infants shifted their gaze from the distracter to the target image within 2000 ms. Swingley and Aslin (2000, p. 9) have argued that saccades initiated more than 2000 ms after the onset of the target word cannot be reliably interpreted as driven by the auditory stimulus.

18 and 24-month-olds

The results of a mixed model ANOVA with the factors naming (pre- and post-naming) and pronunciation accuracy (correct pronunciations; vowel mispronunciations; and consonant mispronunciations) as within-subjects factors and age as a between-subjects factor are presented in Table 6 (reported by items and by subjects, including associated min F' values—significant min F' values are in bold, while near-significant min F' values are in italics). The significant interaction between naming and pronunciation in the main ANOVA suggests systematic differences in infants' looking behaviour between the pre- and post-naming phase in the three pronunciation conditions. As in Experiment 1 and in earlier studies (Swingley & Aslin, 2000), the absence of a main effect of age or a significant interaction between age and any other factors suggests that there were no systematic differences between the 18- and 24-month-olds. The data from these two age-groups were, therefore, analysed together.

As with the younger infants, correct pronunciations resulted in systematic increments in looking from the pre- to the post-naming phases of the trial ($M = 357$ (CI: 180, 534)). Conversely, neither consonant ($M = -90$ (CI: −364, 184)) nor vowel mispronunciations ($M = -55$ (CI: −338, 226)) resulted in similar increments in looking from the pre- to the post-naming phases of the trial. We also analysed the mean difference in the increment from the pre- to the post-naming phase between the correctly pronounced and the two incorrectly pronounced conditions. There was a significant difference in the increment from the pre- to the post-naming phase between correct pronunciations and vowel mispronunciations ($M = 412$ (CI: 129, 696)). Similarly, there was a significant difference in the increment from the pre- to the post-naming phase between correct pronunciations and consonant mispronunciations ($M = 447$ (CI: 134, 760)). However, the difference in the increment from the pre- to the post-naming phase between vowel mispronunciations and consonant mispronunciations was not significant ($M = 34$ (CI: −323, 392)).

Despite the absence of a main effect of age, or any interactions with age, in order to ensure that the effects reported above were not driven purely by the older infants, we separately analysed only the LLK data from the 18-month-olds. There was a significant interaction between naming and pronunciation at 18 months ($F(2, 25) = 5.741$, $p = .009$). Planned comparisons revealed that there was a significant difference in 18-month-olds' looking behaviour between correct pronunciations and vowel mispronunciations ($M = 526$ ms (CI: 118, 935)). Similarly, there was a significant difference in 18-month-olds' looking behaviour between correct pronunciations and consonant mispronunciations ($M = 617$ ms (CI: 171, 1064)). However, there was no significant difference in 18-month-olds' looking behaviour between consonant mispronunciations and vowel mispronunciations ($M = -90$ ms (−608, 427)).

Latency analysis

Analysis of the response latencies yielded similar results to the LLK and PTL measures. Infants fixated the distracter picture at the disambiguation point (367 ms after onset of the target word) in 45.5% of overall trials. Of these trials, infants switched from the distracter to the target image 80.3% of the time, yielding response latencies for 36.5% of all trials ($.45 \times .80$). Seven infants did not provide latency measures for more than one condition. Consequently, latency analyses were conducted using the data from 48 infants altogether (29 infants for comparison of consonant mispronunciations with correct pronunciations, and 34 infants for comparison of vowel mispronunciations with correct pronunciations).

Consonant mispronunciations. The data from the 29 infants used in the latency analyses for consonant mispronunciations showed that infants took an average of 630 ms to switch from the distracter to the target image upon hearing correct pronunciations of the target label. In contrast, infants took an average of 485 ms to switch from the distracter to the target image upon hearing consonant mispronunciations of the target label. A paired samples *t*-test comparing latencies of responses for correct and consonant mispronunciations confirmed that this effect was significant ($M = 144$ (CI: 14, 274)), i.e., infants shift their gaze away from the distracter picture to the target picture faster if the onset consonant is mispronounced than when it is correctly pronounced. Note that this is precisely the result one would expect if, as Swingley and Aslin (2000) note, a switch latency reflects 'the child's detection of a mismatch between the retrieved semantic category and the initially fixated picture' (p. 151). In this experiment, the target and distracter begin with the same consonant. Hence, an onset consonant mispronunciation will trigger mismatch detection faster than a correct pronunciation.

Vowel mispronunciations. The data from the 34 infants used in latency analyses for vowel mispronunciations showed that infants took an average of 682 ms to switch from the distracter to the target image upon hearing correct pronunciations of the target label. Conversely, infants took an average of 851 ms to switch from the distracter to the target image upon hearing vowel mispronunciations of the target label. A paired samples *t*-test comparing latencies of responses for correct and vowel mispronunciations confirmed that this effect was significant ($M = -168$ (CI: $-322, -14$)).

Age-wise comparisons

The analysis using the data from the 15-month-olds found that there was no significant difference in the increment from the pre- to the post-naming phase between correct pronunciations and vowel mispronunciations. On the basis of these results, it would be possible to suggest that infants at 15 months are not sensitive to mispronunciations of vowels. On the other hand, vowel mispronunciations did not lead to a significant increment in infants' preference for the target from the pre- to the post-naming phase, suggesting the opposing view that infants are sensitive to vowel mispronunciations in familiar words—an interpretation supported by the findings of Experiment 1.

Given the equivocal results of the data from the 15-month-olds when analysed separately, we ran an additional analysis incorporating the data from all the age-groups to see if there were any significant differences in the performance of the 15-month-olds from the older group of infants, especially with regard to their sensitivity to vowel mispronunciations. The difference between the trials presented to the 15-month-olds (wake-up trials prior to the main experiment) and the older infants (no wake-up trials prior to the main experiment) was not large enough to invalidate such a comparison. We ran a mixed model ANOVA with naming and pronunciation (consonant mispronunciations, vowel mispronunciations and correct pronunciations) as within-subject factors and age (15, 18, and 24-month-olds) as a between subjects factor. If the 15-month-olds (in contrast to the 18 and 24-month-olds) were not sensitive to vowel mispronunciations, then we would expect a significant interaction between naming, pronunciation, and age. However, we would not expect a significant three-way interaction if 15-month-olds were as sensitive as the older infants to both vowel and consonant mispronunciations.

The ANOVA confirmed that there was no main effect of age ($F(2, 81) = .60$; $p = .54$) or significant interaction between naming, age and pronunciation ($F(4, 162) = .57$; $p = .68$) or significant interactions between age and any other factors ($N * A$: $F(2, 81) = .62$; $p = .53$; $P * A$: $F(4, 162) = .27$; $p = .89$). However, there was, as expected a significant interaction between naming and pronunciation ($F(2, 80) = 7.88$; $p = .001$). We analysed the effect of age separately for the three mispronunciations pairs. There was no significant interaction between naming, pronunciation and age when comparing vowel mispronunciations and correct pronunciations ($F(2, 81) = .61$; $p = .54$); consonant mispronunciations and correct pronunciations ($F(2, 81) = .61$; $p = .54$) and consonant mispronunciations and vowel mispronunciations ($F(2, 81) = .43$; $p = .65$). Similar results were obtained using the PTL measure. These results indicate that there was no systematic difference in infants' sensitivity between vowel and consonant mispronunciations at 15, 18 and 24 months of age. However, it should be noted that this conclusion is based on a null effect and should, therefore, be treated with caution.

Effects of vocabulary size

We calculated the mean receptive percentile vocabulary size of the infants based on parental OCDI reports (*15 months*: $M = 22\%$; $SD = 11\%$; range = 3—54%; *18 and 24 months*: $M = 47.74\%$; $SD = 28.1\%$; range: 0–100%). We measured the correlation between infants' vocabulary size and their sensitivity to mispronunciations, as measured by the difference in naming effect between correct and mispronounced labels. There was no evidence for any correlation (*15 months*: vowels: $r = -.28$, $p = .13$; consonants: $r = .1$, $p = .3$; *18 and 24 months*: vowels: $r = .10$, $p > .5$; consonants: $r = -.07$, $p > .5$), between infants' sensitivity to mispronunciation and size of infants' receptive vocabulary.

We also calculated the mean productive percentile vocabulary size based on parental OCDI reports (*15 months*: $M = 2\%$; $SD = 2\%$; range: 0–6%; *18 and 24 months*: $M = 35.58\%$; $SD = 37.4\%$; range: 0–100%). We measured the correlation between infants' productive vocabulary size and their sensitivity to mispronunciations, as above. There was no evidence for any correlation (*15 months*: vowels: $r = .22$, $p = 14$; consonants: $r = .23$, $p = .22$; *18 and 24 months*: vowels: $r = -.059$, $p = .72$, consonants: $r = -.27$, $p = .09$). Hence, we found no evidence for a relationship between the phonological specificity of infants' lexical representations and the size of infants' productive or receptive vocabulary (as measured by the OCDI), thereby supporting the findings of Experiment 1 and of earlier studies.

Discussion

Experiment 2 evaluated infant sensitivity to vowel and consonant mispronunciations of a set of eight familiar CVC words. Each consonant mispronunciation involved a change along one-dimension (place or voice) of the onset consonant whereas vowel mispronunciations involved a change along one-dimension (height or backness) of the vowel nucleus. The results of the experiment showed that 15-, 18- and 24-month-olds were sensitive to both vowel and consonant mispronunciations. The evidence for this conclusion was that infants increased their looking, as measured by longest looks and proportional looking times, towards a target referent upon hearing a correct pronunciation of its label but they failed to do so when the label was mispronounced, either on the onset consonant or the vowel nucleus. This finding replicates the vowel mispronunciation effect reported in Experiment 1 and the consonant mispronunciation effect reported in earlier work (Bailey & Plunkett, 2002; Ballem & Plunkett, 2005; Swingley & Aslin, 2002). It is noteworthy that the vowel and consonant mispronunciation effects in Experiment 2 were achieved without any repetition of trials, suggesting that neither depends entirely on repetition of stimuli.

Latency measures also supported the conclusion that infants at 18 and 24 months are sensitive to mispronunciations of familiar labels, though in an unorthodox fashion as far as consonant mispronunciations are concerned. For vowel mispronunciations, the time infants took to switch their gaze from the distracter to the target image was slower than for correct pronunciations of the familiar word. This replicates the latency findings reported by Swingley and Aslin (2000, 2002). However, infants were *faster* to switch to the target following an onset consonant mispronunciation than a correct pronunciation. This effect is opposite to that reported by Swingley and Aslin (2000, 2002) who find a slower switch speed for mispronunciations, whether they involve the vowel or the consonant. It will be recalled that in the current experiments, the target and distracter pairs shared the same onset consonants. This was not generally the case in the Swingley and Aslin studies. As noted earlier, switch latency is typically regarded as reflecting the time taken to detect a mismatch between the retrieved semantic category and the currently fixated picture. In the current study, infant switch sensitivity is perhaps more accurately interpreted as indexing the infants' sensitivity to mismatch between the onset consonant and the *distracter* label.

The results with the 15-month-old infants were more difficult to interpret. On the one hand, infants showed a significant effect of naming following only correct pronunciations. Vowel and consonant mispronunciations did not lead to an increase in infants' preference for the target using either LLK or PTL measures. This might suggest that infants at 15 months show a symmetry in their sensitivity to vowel and consonant mispronunciations. However, there was a significant difference in 15-month-olds' looking behaviour only between correct pronunciation and consonant mispronunciation trials. There was no significant difference in their looking behaviour between correct pronunciation and vowel mispronunciation trials. Although there was no difference in infants' sensitivity to vowel and consonant mispronunciations, the absence of a significant difference in infants' looking behaviour following correct pronunciations and vowel mispronunciations might indicate that 15-month-olds experience greater difficulty in establishing vowel identity than consonant identity when tested concurrently on their sensitivity to both. However, a comparison of infants' behaviour across all the age-groups revealed that there were no systematic differences in infants' sensitivity to vowel and consonant mispronunciations at 15, 18 and 24-months of age. The absence of a consonant–vowel asymmetry found at 18 and 24-months also holds at 15 months.

The data also support the suggestion that the size of the mispronunciation effect reported for vowels and consonants does not differ as young as 15-months of age. This result indicates that infants are just as sensitive to mispronunciations of the vowel nucleus as they are to the onset consonant of familiar, monosyllabic CVC words, at least when assessed using the inter-modal preferential looking task. We may conclude that both consonants and vowels play an important role in constraining access to infants' lexical representations during the early stages of vocabulary development. The importance of vowels in early lexical representation is reinforced by the finding that infants exhibited a symmetry in their sensitivity to vowel and consonant mispronunciations, despite the consonant mispronunciations all being situated in the more salient word-initial position, while the vowel mispronunciations were all word-medial. Indeed, the results of the current study do not support the suggestion that consonants have a privileged status over vowels for early lexical recognition processes early in the second year of life.

General discussion

The two experiments reported here provide a sound empirical foundation for the claim that infants are sensitive to mispronunciations of word-medial vowels in familiar CVC labels when required to identify a target referent in an inter-modal preferential looking task. The results of Experiment 1 indicate that infants recognise such vowel mispronunciations across a wide range of words, certainly by 18-months-old. The performance of the 15-month-olds was less robust: they only showed sensitivity to vowel mispronunciations during the second block of testing. These findings complement and extend those of Swingley and Aslin (2000, 2002) who reported infant sensitivity to vowel mispronunciations of two familiar words in a similar task.

The results of Experiment 2 demonstrated that infants as young as 15-months of age were equally sensitive to vowel-medial and onset consonant mispronunciations of familiar, monosyllabic, CVC words when required to identify a target referent, even when the mispronunciations involved just a single featural change. This result indicates that the identity of onset consonants and vowel nuclei are equally potent in constraining lexical recognition by infants during the second half of the second year of life.

However, the results with the 15-month-olds were, again, less robust. Although these infants did not show a significant effect of naming for vowel mispronunciations, there was no difference in infants' looking behaviour following vowel mispronunciations and correct pronunciations. In contrast, consonant changes produced a mispronunciation effect. This contrast points to the conclusion that 15-month-olds possess more fragile representations of vowels than consonants in familiar words. However, there was no difference in infants' looking behaviour following consonant mispronunciations and vowel mispronunciations. Neither was there a difference in infants' looking behaviour at 15, 18 and 24-months of age, providing support for the conclusion that 15-month-olds are equally sensitive to vowel and consonant mispronunciations. We suggest that a more complete picture of 15-month-olds' comparative sensitivity to vowel and consonant mispronunciations requires testing on a number of different issues. For instance, the consonant mispronunciations were always word-initial, while the vowel mispronunciations were word-medial, stacking the deck in favour of infants being sensitive to the word-initial consonant mispronunciation. This was a constraint imposed by the relative infrequency of vowel-initial words in the infant lexicon. The absence of a significant difference in infants' looking behaviour following vowel mispronunciations and correct pronunciations may have been motivated by the position of the mispronunciation within the word, rather than the identity of the mispronunciation. Importantly, despite the odds being in favour of the consonant mispronunciations, infants display sensitivity to vowel mispronunciations as early as 15-months of age—providing support for the view that vowels and consonants are equally well-specified early in the second year of life. Note, however, that our conclusion of a symmetry in 15-month-olds' sensitivity to vowel and consonant mispronunciations was based on a null effect, hence, our interpretation of this finding is not definitive.

The primary finding of Experiment 2 is that vowels and consonants constrain lexical access equally early in the second year of life. Previous research by Nazzi (2005) suggests that consonants have a privileged status in lexical acquisition. Nazzi found that 20-month-old French infants were able to simultaneously acquire two words that differed only by a single consonant, while not being able to learn two words that differed by a single vowel. There are a number of reasons for the behavioural differences between the infants in the current study and Nazzi's experiment. First, Nazzi's experiment employed novel words, while the current study presented infants with highly familiar words. Earlier experiments have found that there are differences in the phonological specification of novel and familiar words. For instance, Stager and Werker (1997) found that 14-month-olds have difficulty learning to associate two phonetically minimal novel words with two *novel* objects (e.g., 'bih' and 'dih')—suggesting underspecification of novel words. Using a similar habituation task, however, Fennell and Werker (2003) found that 14-month-olds are sensitive to violations of object-label pairings of two phonetically similar *familiar* words (e.g., 'ball' and 'doll')—infants look longer at a target image when the image does not match the label than when it does. These findings are consistent with the hypothesis that familiar words may possess a greater level of phonological specificity than novel words. This interpretation provides one possible explanation for the differences between Nazzi's results and those of the current study.

Second, Nazzi employed a novel word-learning task which required infants to learn two very similar novel words and categorise three objects based on these novel labels. Word-learning tasks can be highly demanding, to say nothing of the added computational requirements of the categorisation task. This may require infants to ignore information that is normally accessed when listening to familiar words. For example, Stager and Werker (1997) found that 14-month-old infants could readily learn two novel words which were not minimal pairs (e.g., 'lif' and 'neem'). In contrast, the current study merely required infants to notice a match between a familiar target object and a target label, where a label corresponding to the distracter image shared *only* the onset consonant with the target label. It is conceivable that the lack of any differences between vowel and consonant mispronunciations in the current study was driven by the low processing demands associated with the preferential looking task: making the task more difficult might reveal a difference between vowel and consonant sensitivity, even in 18-month-olds.

Third, in his study, Nazzi presented infants with similar-sounding monosyllabic and bisyllabic word-pairs. His conclusion that vowels are less central then consonants in constraining lexical access is based on results averaged across these mono- and bisyllabic words. However, his French infants were successfully able to learn two monosyllabic novel words differing only in a minimal vowel in one of three monosyllabic conditions ($p < .001$). Conversely, infants performed significantly below chance when required to learn two complex bisyllabic words differing only in the vowel in the initial syllable ($p < .03$). It is possible that learning monosyllabic words makes it easier for infants to pay more attention to all the phonological information present in the stimuli. This would be entirely consistent with the results reported in the current study, since infants were presented only with monosyllabic words and were able to distinguish correct and incorrect pronunciations in the service of identifying a referent.

We have argued that the difference between Nazzi's results and those of the current study might be attributed to the novelty of the stimuli and that the complexity of the bisyllabic stimuli may be detracting from vowel sensitivity. However, Ballem and Plunkett (2005) suggest that novel word representations may be more phonologically specified than previously assumed. Hence, if novel words are not underspecified, the difference between Nazzi's results and the current study would appear to implicate the syllabic complexity of the stimuli tested.

An alternative source of the differences between the current study and Nazzi (2005) might lie in cross-linguistic differences between the vowel systems of French and English. The French inventory is larger than English and possesses a greater number of feature contrasts than English. Earlier studies have suggested that phonological representations of sounds increase in specificity with increase in the size of the vowel inventory of the language (Bohn, 2004). However, contrary to the differences we have found between Nazzi (2005) and the current study, this would predict that English infants would be less sensitive to vowel mispronunciations than French infants.

On the other hand, Frisch, Pierrehumbert, and Broe (2004) have argued that an increase in the number of contrastive features shared by the vowels in a language may lead to greater perceived similarity between the vowels. Consequently, English infants may be more sensitive to vowel mispronunciations in words than French infants. It should be noted that perceived similarity cannot be calculated without careful consideration of the number and nature of the contrastive features defining the phonological inventory. Hence, this cross-linguistic account must remain speculative.

Conclusion

Early lexical representations of familiar words contain adequate information for very young English infants to detect mispronunciations of the vocalic nucleus of a target label. The results from the three age groups tested indicate that this vowel sensitivity is in place by 15-months-old. These findings constitute the first experimental evidence that vowel identity constrains lexical access for a wide range of monosyllabic, familiar words at an early stage of lexical development. We found no evidence of a relationship between vowel sensitivity and vocabulary size and so no support for the view that the density of lexical neighbourhoods is a factor driving phonological specificity of words.

The similarity in infants' sensitivity to mispronunciations of vowels and consonants during lexical recognition found in this study offers some qualifications to that of the recent study by Nazzi (2005) who argues that his findings might "be interpreted as the first piece of evidence for a greater reliance on consonants at the lexical level in infancy" (p. 28). Our findings rule out the possibility that consonants play a more pivotal role than vowels in lexical processing in infancy, at least in recognition of familiar words at 18 months of age. Both consonants and vowels constrain lexical recognition equally in the latter half of the second year of life.

There are many questions regarding the role of vowels in lexical recognition in infancy that the current study leaves unanswered. Definitive conclusions regarding the importance of vowels in lexical representation are contingent upon further empirical validation of the robustness of vowel mispronunciation effects in the recognition of novel and familiar words, and mono- and bisyllabic words. Exploration of cross-linguistic factors might also influence our understanding of the role of vowels in lexical access. For example, languages like Danish and Swedish have almost twice the number of vowels as English and would provide a test case for exploring the influence of cross-linguistic differences on vowel mispronunciation effects.

Future studies could also attempt to isolate the developmental onset of vowel mispronunciation effects: all the age-groups tested in the current study showed some sign of sensitivity to vowel mispronunciations. Vowel-specific phonological characteristics may also influence the importance of vowels in lexical access: some vowel changes may be more perceptually salient than others. Earlier studies have suggested that there are perceptual asymmetries in vowel discrimination such that a vowel change from a less peripheral vowel (in terms of location in formant space) to a more peripheral vowel is more easily discriminable than a change the other way around (Bohn & Polka, 2001; Polka & Bohn, 2003). While not all vowel changes have been tested for asymmetries, this finding presents a theoretical perspective that can be used to compare the impact of vowel changes presented to infants. Furthermore, the mispronunciations in the current study involved the backness, height, and/or roundedness of the vowel. There may be differences in the salience of individual featural changes, with changes in one feature being perceptually (and possibly acoustically) more discriminable than changes to another feature.

Finally, there is a caveat to the conclusions drawn by the current study. We have argued that infants were sensitive to changes to the vowels of the words presented to them. However, there are likely to be vowel–consonant co-articulation effects that might lead to significant differences in the acoustic characteristics of the consonant between the correctly pronounced and mispronounced words. Infant performance might have been triggered by the acoustic differences in the co-articulated consonants between the correct and incorrect pronunciations rather than because of the changes to the vowels themselves. On this interpretation of the results, sensitivity to mispronunciations would be led by differences in the acoustic characteristics of the consonant and not the vowel. While this suggests a less pivotal role for vowels in lexical representation, there is no empirical evidence suggesting that infants' performance is dependent on the acoustic characteristics of the co-articulated consonant *alone*.

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Appendix A

Differences between one- and many-dimension mispronunciations

While it is always difficult to quantify the different degrees of vowel mispronunciations, in this section we attempt to find out if infants' display any sensitivity to the size of the mispronunciation presented to them. Experiment 1 was not specifically designed to investigate the impact of the degree of vowel mispronunciation. However, infants were presented with different kinds of mispronunciations, specifically varying between one-dimension changes and many-dimension changes. The three dimensions considered crucial in this study were vowel height, backness, and roundedness. We analysed whether infants showed any difference in their sensitivity to mispronunciations that involved one-dimension changes to the vowel compared to mispronunciations that involved more than two- or three-dimension changes to the vowel. Tables 1 and 2 report the number of dimensions differentiating the correct and incorrect pronunciations of the words presented to infants.

We only considered those infants who were presented with an equal number of one- and many-dimension mispronunciations (i.e., 1 trial per condition per infant at 15 months and 2 trials per condition per infant at 18 and 24 months), in order to ensure similar variability in each condition. This permitted analysis of 8 15-month-olds (from Block 2), 12 18-month-olds, and 15 24-month-olds. We then computed the mispronunciation effect separately for one- and many-dimension mispronunciations. This was calculated as the difference in the increment from the pre- to the post-naming phase between correct pronunciation and either kind of mispronunciation trials (i.e., $[(\text{post}_{\text{correct}} - \text{pre}_{\text{correct}}) - (\text{post}_{\text{mis1}} - \text{pre}_{\text{mis1}})]$ for one-dimension mispronunciations and $[(\text{post}_{\text{correct}} - \text{pre}_{\text{correct}}) - (\text{post}_{\text{mis-many}} - \text{pre}_{\text{mis-many}})]$ for many-dimension mispronunciations).

15 months

Fifteen-month-olds do not show a significant mispronunciation effect for one-dimension mispronunciations (LLK: 151 ms (CI: −939, 1241); PTL: .19 (CI: −.16, .56)), but did show a significant mispronunciation effect for many-dimension mispronunciations (LLK: 1425 ms (CI: 491, 2371), $d = .63$; PTL: .38 (CI: .03, .72), $d = .54$). The difference between these mispronunciation effects was significant using the LLK measure ($M = 1284$ (CI: 325, 2243), $d = .54$) but not the PTL measure ($M = .18$ (CI: −.24, .61)). Fifteen-month-olds appear to be more sensitive to many-dimension mispronunciations than to one-feature mispronunciations.

18 months

Eighteen-month-olds do not show a significant mispronunciation effect for one-dimension mispronunciations (LLK: 522 ms (CI: −649, 1694); PTL: .13 (CI: −.13, .41)) or for many-dimension mispronunciations (LLK: −122 ms (CI: −1364, 1119); PTL: −.03 (CI: −.29, .22)). There was no significant difference between infants' looking behaviour following one- and many-feature mispronunciations using the LLK measure ($M = -644$ (CI: −2241, 951)) or the PTL measure

($M = -.17$ (CI: $-.50, .15$)). Hence, 18-month-olds show sensitivity to vowel mispronunciations of familiar words but apparently do not recognise differences in the size of the mispronunciation. However, the amount of variance within the small sample ($N = 12$) might provide some explanation for the failure to separately find an effect of sensitivity to one-dimension and many-dimension mispronunciations at 18 months. Hence, interpretation of the results of this analysis must remain cautious.

24 months

Twenty-four-month-olds do not show a significant mispronunciation effect for one-dimension mispronunciations (LLK: -241 ms (CI: $-829, 345$); PTL: $-.07$ (CI: $-.24, .08$)), but show a near-significant mispronunciation effect for many-dimension mispronunciations (LLK: 327 ms (CI: $-67, 722$); PTL: .06 (CI: $-.07, .20$)). However, there was a significant difference between infants' looking behaviour following one- and many-feature mispronunciations using the LLK measure ($M = 569$ ms (CI: 72, 1465), $d = .39$) and the PTL measure ($M = .14$ (CI: .02, .25), $d = .35$). Hence, at 24 months of age, infants appear to be more sensitive to many-dimension mispronunciations than to one-dimension mispronunciations. While the Cohen's '*d*' values confirm that the effects reported in this analysis are large, there is, however, cause for some concern over the size of the sample in the different age-groups. None of the analyses using this reduced dataset yielded a significant mispronunciation effect for one-dimension mispronunciations at 15, 18 or 24 months. This might suggest that infants are only sensitive to large mispronunciations of the vowels in familiar words. However, the absence of a significant mispronunciation effect for one-dimension mispronunciations might also be explained by the lack of power in the analysis. Indeed, the lack of comparability between the mean difference in looking times presented in the current analysis and those in the main analysis advise against placing too much emphasis on the results of the current analysis.

The results of Experiment 2, where only one-dimensional changes were tested, indicate that 15- to 24-month-old infants are sensitive to small changes to vowels of familiar words. Nevertheless, the fact that the small dataset analysed in this appendix yields a significant result for large changes but not for small changes also indicates that infants are sensitive to the size of the mispronunciation with which they are presented.

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