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Nine-month-olds use frequency of onset clusters to segment novel words

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Abstract

Before their first birthday, infants have started to identify and use information about their native language, such as frequent words (Bortfeld, Morgan, Michnick Golinkoff, & Rathbun, 2005), transitional probabilities (Saffran, Aslin & Newport, 1996), and co-occurrence of segments (phonotactics; Mattys, Jusczyk, Luce & Morgan, 1999; Mattys & Jusczyk, 2001) to identify viable word boundaries. These cues can then be used to segment new words from running speech. We explore whether infants are capable of detecting a novel word form using the frequency of occurrence of the onset alone to further characterize the role of phonotactics in speech segmentation. Experiment 1 shows that English learning 9-month-olds can successfully segment a word from natural speech if the onset is legal in English (i.e., pleet) but not if the onset is illegal (i.e. tleet). Experiment 2 shows that English learning 9-month-olds are successful at word segmentation when presented with two onset clusters that vary in statistical frequency. Infants familiarized to a high frequency onset (i.e., trom) were successful at segmenting the target word embedded in speech, but those familiarized to the low frequency onset (i.e., drom) were unsuccessful. Together, these results show that infants use statistical information from the speech input and that low levels of exposure to onset phonotactics alone may not be sufficient in identifying word boundaries.

Keywords: language development, infant speech perception, word segmentation, frequency, phonotactics

Nine-month-olds use frequency of onset clusters to segment words

Adults have large, dynamic lexicons that bolster their knowledge of the language-specific cues that are necessary for speech processing. Cues like phonotactics[1] or prosody help adults detect words in continuous speech, especially when interacting with probabilistic information (Finn & Hudson Kam, 2008; Shukla, Nespor, & Mehler, 2007). Infants, however, experience a vast mixture of acoustic information and are in the process of determining what ‘word finding’ cues are available in their native language. They must rely on different sources of information to discover cues and patterns that aid in word segmentation (for a review see Curtin & Archer, 2015). Using highly frequent words (e.g., *mommy*; Bortfeld, Morgan, Michnick Golinkoff, & Rathbun, 2005) and words at utterance edges (Johnson, Seidl, & Tyler, 2014) infants can segment new words from speech at 6 months. Around 7 to 9 months, infants are capable of tracking the predominant stress pattern of their language (Curtin, Mintz, & Christiansen, 2005), and syllable co-occurrences (transitional probabilities (TPs); Saffran, Aslin, & Newport, 1996) in artificial languages, but when English-learning infants are exposed to TPs in a novel natural language (i.e., Italian), they segment only when isolated words are included in the speech stream (Lew-Williams, Pelucchi, & Saffran, 2011). Previous exposure to phonological templates also helps inform infants’ segmentation (Saffran & Thiessen, 2003). When presented with repeated words within passages of natural speech, infants can extract CVC target words, (*feet*, *cup*). Further, they recognize only those test items that are an exact match to those with which they were familiarized (Jusczyk & Aslin, 1995).

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[1] Phonotactics are language-specific combinations and positions of speech sounds within a word.

Thus, by the second half of their first year, infants have experience with and use a number of segmentation cues. Here we focus on infants' use of native-language phonotactic information to identify new words. Specifically, we ask whether infants' knowledge of stop-liquid[2] onsets[3] influences their segmentation of novel words from speech.

Infants show preferences for native-language phonotactics by approximately 9 months (Jusczyk Friederici, Wessels, Svenkerud & Jusczyk, 1993). They are sensitive to onset cluster frequency (Archer & Curtin, 2011) and show preferences for onset and coda clusters that conform to native phonotactics over those that do not (e.g. *bref* over illegal *febr*; Friederici & Wessels, 1993). They also prefer novel words with high probability segment co-occurrences to low probability ones (Jusczyk, Luce, & Charles-Luce, 1994). Bilingual infants also prefer the phonotactic patterns of the dominant language in their input (Bosch & Sebastián-Gallés, 2001).

Phonotactic sensitivity helps infants detect viable word boundaries in speech. Nine-month-olds detect the difference between consonants that cross a syllable boundary from those that cross a word boundary (Mattys, Jusczyk, Luce & Morgan, 1999). For example, in English the string CV**ŋ**.**k**VC is an allowable within-word consonant sequence between syllables. However, a string, such as CV**f**.**h**VC, is only observed in English between words. Infants of 9 months prefer within-word phonotactic combinations, suggesting knowledge of legal word forms and syllable boundary phonotactics (Mattys et al., 1999). Similarly, 9-month-olds exposed to strong phonotactic boundary cues (e.g., *bean**gaffe**hold*) and then tested on isolated target words (e.g., *gaffe*) demonstrate a preference for target words, while infants exposed to poor boundary

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[2] Stops are a category of consonants created by stopping airflow and releasing (e.g., p, b, t, d, k, g). Liquids are a category of resonant consonants created by voicing and semi-restricted airflow around the tongue (e.g., l, r).
[3] Onsets are consonants that are positioned at the beginning of a syllable.

cues (e.g., *fang**gaffe**tine*) do not (Mattys & Jusczyk, 2001). Moreover, by 8 months, infants will use high (but not low) phonotactic probability between syllable sequences as viable labels for categories (Erickson, Thiessen, & Graf-Estes, 2014). Together, these studies demonstrate the usefulness of phonotactic information for infants in identifying words and forming categories.

Native-language sensitivity of co-occurrences also informs word mapping and recognition. Twelve-month-olds map novel words containing legal onsets onto objects (e.g., *plot*), but not those that contain illegal ones (e.g., *ptak*; MacKenzie, Curtin, & Graham, 2012). After familiarization to an artificial continuous stream of speech, infants of 17 months map highly probable phonotactic labels to objects, but not low probability ones (Graf-Estes, Evans, Alibali, & Saffran, 2007), suggesting that prior segmentation, and not just mere exposure to forms, influences word-object mapping. Further, when 18-month-olds are presented with either two phonotactically legal or two illegal labels paired with novel objects, they look longer at the correct objects after hearing the legal labels (Graf-Estes, Edwards, & Saffran, 2010). By 19 months, they use both lexical stress and phonotactic probabilities in bisyllabic novel words to determine appropriate labels for novel objects (Graf-Estes & Bowen, 2013). Thus, even in the early stages of word learning, infants' willingness to map labels to objects is constrained by phonotactic knowledge.

Importantly, these studies demonstrate that infants have a burgeoning knowledge of how speech sounds combine to create word forms. That is, infants can identify whether combinations of speech sounds are allowable as words (e.g., English: *plok*, *blick*) or not (e.g., *ptak*, *bnick*) regardless of whether word forms have meaning. By 9-months, infants are not only sensitive to native-language phonotactics but also to statistical information in general (e.g., Archer & Curtin, 2011; Jusczyk et al. 1994), and detect word boundaries where they encounter unlikely speech sound combinations (Mattys et al., 1999; Mattys & Jusczyk, 2001). The aim of the current study is to determine whether infants can successfully segment novel words from fluent speech based on their knowledge of combinations in word onsets through experience with their native language.

Experiment 1

We investigated 9-month-olds' use of native language onset clusters in segmenting words from fluent speech. Specifically, we examined infants' use of legal (*pleet* [plit]) versus illegal (*tleet* [tlit]) onset clusters. If 9-month-olds are capable of identifying a word boundary signalled by knowledge of an onset cluster, we predict that only those infants exposed to legal onset clusters (*pleet*) will look differentially at the test items even though infants in both groups have equal exposure to the embedded target.

Methods

Participants

Forty-eight 9-month-olds (Mean: 9.45, SD: .316, Range: 8.89 – 10.33) from primarily (i.e., greater than 80%[4]) English speaking homes participated in this study. Twenty-four infants were included in each group: the *legal onset* group (13 females), and the *illegal onset* group (11 females). An additional 14 infants were removed from the analysis because of technical errors (n = 3), experimenter error (n = 4), distraction (n = 4), and crying (n = 3).

Stimuli

[4] Four of the infants were exposed to more than 20% of a second language in the home. Each infant had approximately 50% exposure to English. Of these second languages, 2 infants heard French in the home, one infant heard Spanish, and one infant heard German. Since word initial /tl/ is phonologically illegal in French, Spanish, and German, these data were included.

A female native speaker of English recorded the auditory stimuli in infant-directed speech (See Figure 1a). Each familiarization passage consisted of 6 sentences, each containing a CCVC target word (i.e., *pleet* or *tleet*) in either sentence medial or final position (see Figure 1b). Separate lists of isolated target words were also recorded. Infants heard a maximum of 12 tokens of either *pleet* or *tleet* during the test phase.

------- [FIGURES 1a and 1b HERE] -------

Procedure

Using a modified version of the head turn procedure (Jusczyk & Aslin, 1995), two groups of English learning 9-month-olds were familiarized to either phonotactically legal (*pleet* [plit]) or illegal (*tleet* [tlit]) novel words embedded within passages of natural speech. Infants were seated on their caregiver's lap facing a central monitor (two other monitors were mounted on the side walls). A pre-test trial began the experiment in which the infants heard a 20 second clip of classical music paired with a waterwheel on the center monitor. Then, on the same monitor, infants were familiarized to 4 trials of 6 sentences, each with a fixed duration of 15 seconds while watching a glowing ball[5]. Four familiarization trials each consisted of 6 sentences in different orders. In the legal condition, infants heard *pleet* embedded in each sentence, and in the illegal condition, the infants heard *tleet* in the same sentences. A contingency phase followed using tones to teach the contingency between the side monitors and sound presentation. Four trials of tones paired with a visual stimulus (glowing ball), alternated to the left and right monitors, and looks away over 2 consecutive seconds terminated the trial. Immediately after, the

[5] In their seminal work, Jusczyk & Aslin (1995) familiarized 7.5-month-olds to passages with an approximate duration of 78.88 seconds (based on a total of 4 trials of 2 target words (2 trials per word)).

infant-controlled test phase began. Both groups heard the same test trials consisting of 6 lists of each isolated target words: 3 trials of *pleet* and 3 trials of *tleet*. Trial orders were semi-randomized and controlled for side (left, right) and word (*pleet*, *tleet*) with a limit of 2 consecutive side or word trials. Looking time to each side monitor was recorded.

Apparatus

Infant testing took place in a dimly lit, sound attenuated booth (2.74 m x 1.82 m). Infants sat approximately 1.5 m away from the center monitor, with two monitors mounted on the side walls, equidistant from the infant. All three monitors were identical (65 cm wide x 49 cm high). Auditory stimuli were delivered at 70 dB, +/- 5 dB, through BOSE speakers located below each monitor. Infant gaze was recorded using a digital video camera and transmitted to the experimenter in the control booth via close circuit television. Parents listened to music through noise cancellation headphones used to mask the stimuli.

Habit X 1.0 (Cohen, Atkinson, & Chaput, 2004) was used to present stimuli to the infants while the experimenter recorded looking time by pressing a designated key on the computer keyboard during infant looks to the visual stimuli. Looking time was coded offline frame-by-frame using Super Coder (Hollich, 2005). Cronbach's alpha was calculated as the reliability statistic. To measure inter-rater reliability of test trials, 20% of the data (10 infants) were coded by a second coder and reliability was achieved (Cronbach's $\alpha = .997$).

Results

Results from pairwise t-tests (two-tailed) for the legal (*pleet*) condition showed a significant difference between the familiar (*M*: 7.51, *SD*: 2.99) and novel (*M*: 8.72, *SD*: 2.62) trials, $t(23) = -2.503$, $p = .020$, $d = .511$). The illegal (*tleet*) condition did not show significant differences between the familiar (*M*: 8.75, *SD*: 2.33) and novel (*M*: 8.53, *SD*: 2.26) trials, $t(23) = .410$, $p = .685$, $d = .084$ (see Figure 2; see Appendix B for looking direction per infant).

------------ [FIGURE 2 HERE] -----------

Experiment 1 demonstrates that infants are sensitive to whether an onset sequence is present or absent in their language. This does not necessarily mean, however, that the mere presence of co-occurring speech sounds within a language is enough to indicate the presence of a word boundary to 9-month-old infants. Infants track the statistical frequency and probability of phonotactic combinations (Jusczyk et al., 1994; Archer & Curtin, 2011) so perhaps they use their experience with stop-liquid onsets in segmenting words from speech. In Experiment 2, we investigate whether input frequency of stop-liquid onsets has an effect on infants' detection of word boundaries.

Experiment 2

Here we ask whether infants recognize a complex onset as a viable word boundary when it is under represented in the input, but still legal.

Methods

Participants

Forty-eight 9-month-olds (Mean: 9.57 SD: .265, Range: 9.02 – 10.03) from monolingual English speaking homes participated in this study, with only one infant exposed to French at home, approximately 15% of the time. Twenty-four infants were exposed to high frequency onset cluster (*trom*) stimuli (13 females) and 24 were exposed to low frequency (*drom*; 12 females). An additional 18 infants were excluded because of technical errors (n = 9), experimenter error (n = 1), fussiness or distraction (n = 4), over a month premature (n = 1), and zero looking time for at least one trial (n = 3).

Stimuli

The same speaker rerecorded all stimuli from Experiment 1 changing the target words to *trom* and *drom*. The clusters /tr/ and /dr/ were chosen based on Archer & Curtin's (2011) corpus analysis in which /tr/ was considered high type frequency[6] and /dr/ was considered low type frequency (see Appendix A). Familiarization phase stimuli were matched in content and intonation as Experiment 1 (see Figures 3a and 3b). Test stimuli were also matched to Experiment 1.

------- [FIGURES 3a and 3b HERE] ---------

Procedure

Identical to Experiment 1.

Apparatus

Identical to Experiment 1.

The data of 10 infants were measured for inter-rater reliability using Cronbach's alpha, as in Experiment 1. Inter-rater scores were reliable, Cronbach's α = .999.

Results

We ran analyses of each condition using pairwise t-tests. In the high frequency condition (*trom*; n = 24), the novel word (*drom*) showed a significantly higher mean looking time (*M*: 8.28, *SD*: 2.76) than the familiar (*trom*) (*M*: 7.07, *SD*: 2.77), $t(23) = -2.087$, $p = .048$, $d = .430$). However, the low frequency condition (*drom*), showed no difference between the familiar (*M*:

[6] Type frequency is counted by including every lexical entry featuring a specific onset as 1. For example: problem, prank, pray, preach would be calculated as 4 regardless of the number of instances for each word. Token frequency count includes all instances of each word that features a particular onset. For example: problem (x 5), prank (x 2), pray (x 1), preach (x 4) would sum to a token frequency of 12 for /pr/.

9.20, *SD*: 3.51) and novel (*M*: 8.86, *SD*: 3.41) trials, $t(23) = .426$, $p = .674$). See Appendix B for looking direction per infant.

------------ [FIGURE 4 HERE] -----------

General Discussion

Infants' understanding of their native language accumulates with experience, but not all co-occurrences of speech sounds are equally represented in the input. Our findings indicate that young infants might not always be capable of using low type frequency speech sound combinations to segment word forms, even if they are attested in ambient speech, suggesting additional experience and/or other cues are required to determine the status of these sound combinations. The infants in our study segmented forms based on their overall occurrence in the ambient language, excluding low frequency phonotactics as viable word onsets due to insufficient experiences with these forms in the input. Results in the legal and high frequency conditions of experiments 1 and 2 show that infants' acquired knowledge of phonotactics is crucial for success in this task. Though embedding a target word in natural speech could provide the infants with more information than simply the phonotactics of the onset, it was recognition of the onsets /pl/ and /tr/ that was vital to identifying a word boundary, whereas onsets underrepresented in the input (zero frequency /tl/, low type frequency /dr/) were not used for segmentation, even though common dr-words are readily present in spoken language (e.g., drink, dress, draw). Importantly, both groups heard equal number of tokens of the target words during familiarization, thus exposure alone was not sufficient for segmentation.

It is possible to interpret the findings another way. The determiner 'a' was included in 5 of the 6 sentences to simulate a natural context for singular nouns. In natural speech, nouns are often preceded by function words and, although it is unlikely 9-month-olds understand the semantic function of a determiner, infants are capable of discriminating function from content words at a very young age based on their acoustic properties (Shi, Morgan, & Werker, 1999). The inclusion of ‘a’ could have been interpreted as an unstressed syllable which would change each word to a bi-syllabic iamb (e.g., ‘a pleet’ to ‘apleet’)[7]. However, since infants familiarized in the zero or low frequency conditions were not successful, it is unlikely that the determiner was responsible for successful segmentation. Also, English-learning 9-month-olds find it more difficult to segment an iambic novel word based on their experience with English trochees (see Thiessen & Saffran, 2003). Thus, even with the availability of this distributional information, infants familiarized to *tleet* or *drom* were not successful at segmentation.

Eighteen-month-olds segment highly probable word forms and use these segmented forms as labels for objects (Graf-Estes et al., 2007; also see Graf-Estes & Bowen, 2013). By 12 months, English-learning infants are able to attach phonotactically legal words to novel objects, but not illegal words (MacKenzie et al., 2012; see Graf-Estes et al., 2010 for similar results at 18 months). By tracking highly probable combinations of speech sounds, infants can recognize these forms as good word candidates. The results of the current study support these findings.

It is possible that a longer exposure phase could have changed infants’ segmentation outcomes. Chambers and colleagues (2003) familiarized 16-month-olds to lists of non-words that followed a specific phonotactic pattern for approximately 4 minutes. Conditions were legal or illegal depending on exposure in the familiarization phase, though all patterns were actually legal in English. At test, infants detected differences between the familiarized and novel patterns, therefore conditioning infants to accept the phonotactic patterns in the familiarization phase as

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[7] See Appendix A (Table 3) for frequency counts of ‘a’ + stop-liquid onset combinations between words (e.g., ‘a pleet’) and within-word (e.g.,‘apleet’).

legal. 'Illegal' phonotactics were not included in the familiarization and therefore were novel to the infants at test (e.g., *pab* /pæb/ but not *bap* /bæp/). In our study, a longer familiarization phase might have induced the infants to accept *tleet* and *drom* as segmentable forms. Indeed, infants must eventually segment low frequency phonotactic word forms, like *drom*, to correctly identify existing lexical items in their language. That is, since there exist lexical items with low probability phonotactics within a language, it must be the case that these forms are still learnable through experience with language. It is likely that the accumulation of exposure to all legal phonotactic combinations and positions leads to storage of information for use in word segmentation and learning. While we cannot rule out that uncommon phonotactics hinders segmentation, the evidence presented here supports our assertion that experience facilitates segmentation.

These findings also support the literature positing that infants' representations are robust enough to allow identification of a word form when the competing word form is minimally contrastive (e.g., *pleet – tleet*). Jusczyk and Aslin (1995) showed that infants of 7.5 months are capable of segmenting CVC words (e.g., *cup, feet*), but do not recognize them when the onset is switched (e.g., *tup, zeet*) or when the coda is switched (e.g., *cut, feek*; Tincoff & Jusczyk, 2003), suggesting that their representations are detailed enough to detect the fine contrast. That infants showed a novel preference for *tleet* when familiarized to *pleet* (and *drom* when familiarized to *trom*) suggests that the representations formed with the higher frequency onsets were accurate enough to distinguish them from the minimally contrastive low frequency or illegal onsets at test. Further, the infants in the legal and high frequency conditions were capable of segmenting the whole form using the onset cues only. There is an emerging body of research that suggests that consonants in coda position become salient to infants over time and with language experience. It is not until 16 months of age that voicing or place of articulation in word-final codas can be discriminated by Dutch infants (Zamuner, 2006). Further, 12-month-olds are capable of detecting differences in stop codas only when they are both voiced and in word-final coda position (e.g., *ab* – *ag*), as opposed to voiceless (e.g., *ap* – *ak*) or in word-medial (e.g., *apta* – *akta*, *abta* – *agta*) coda position (Archer, Zamuner, Engel, Fais, & Curtin, 2015). In a study by Wang and Seidl (2014), 12-month-olds were familiarized to bisyllabic non-words in which fricatives were embedded in onset position of the second syllable (CVC.FVC). The infants were capable of learning this pattern, but not when the fricative was embedded in the coda position (CVF.CVC). At 8 months, infants did not learn either pattern, but 15-month-olds learned both. Our study embedded target words within natural speech. It is possible that the detailed representation formed during the familiarization is the result of strong phonotactic cues within the target word along with other cues. For instance, the distribution of the phonetic information immediately following the coda consonant might help infants form a more robust representation of the whole form (e.g., *cup* – *cut* (Jusczyk & Aslin, 1995) or *pleet* - *tleet* where the infants recognized the whole form of *pleet* though the coda cues were identical to *tleet*, see Figures 1a and 1b).

The findings of our study demonstrate that phonotactics are indeed a powerful cue for the detection of word boundaries. We have shown that 9-month-olds track the statistical information of speech sound combinations from the ambient language and use this information to subsequently locate viable word forms in fluent speech. In this case, higher frequency onsets helped infants segment whole words in natural, infant-directed speech. Thus, infants extract statistical information from their emerging knowledge of phonotactics to cue word boundaries in their language.

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Figure 1a. Spectrogram of *pleet* and *tleet* sample familiarization sentences with pitch contour.

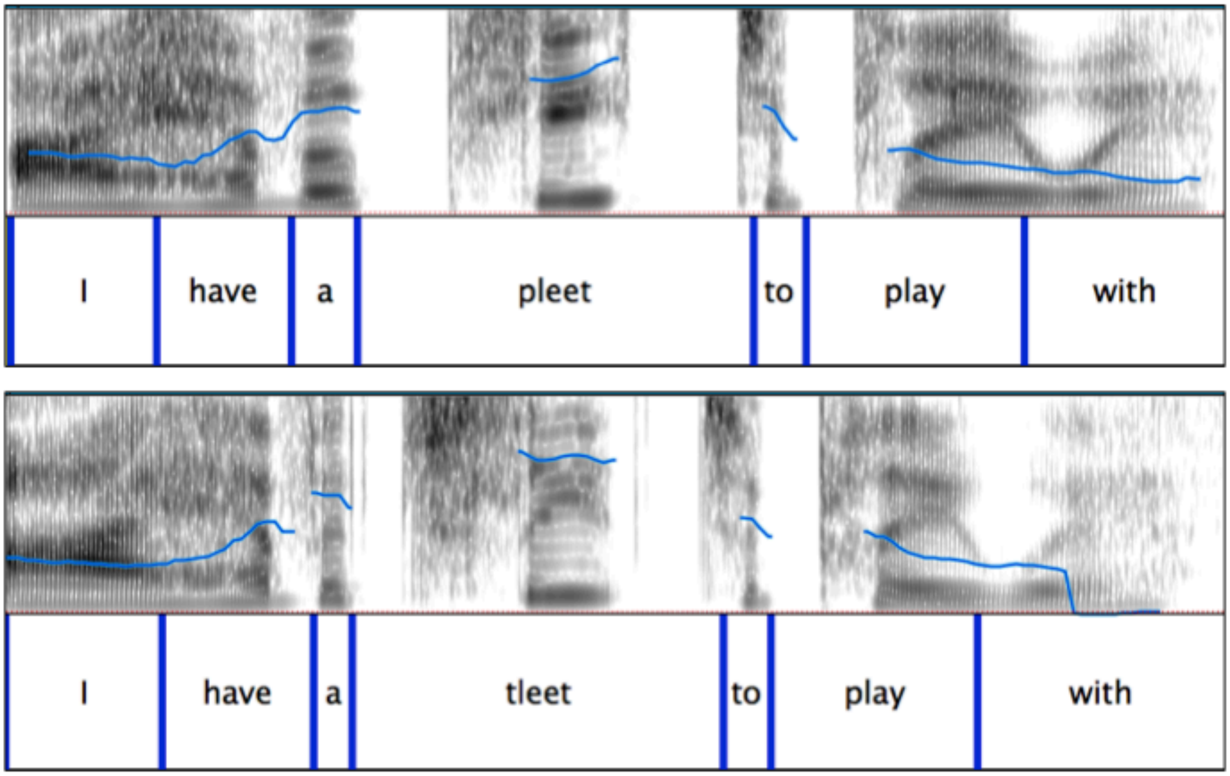
Figure 1b. Familiarization stimuli for Experiment 1.

Figure 2. Mean looking time in seconds for legal and illegal familiarization conditions. Error bars denote SE (Standard Error). Asterisk denotes $p < .05$.

Figure 3a. Spectrogram of *trom* and *drom* sample familiarization sentences with pitch contour.

Figure 3b. Familiarization stimuli for Experiment 2.

Figure 4. Mean looking time in seconds for high frequency and low frequency familiarization conditions. Error bars denote SE (Standard Error). Asterisk denotes $p < .05$.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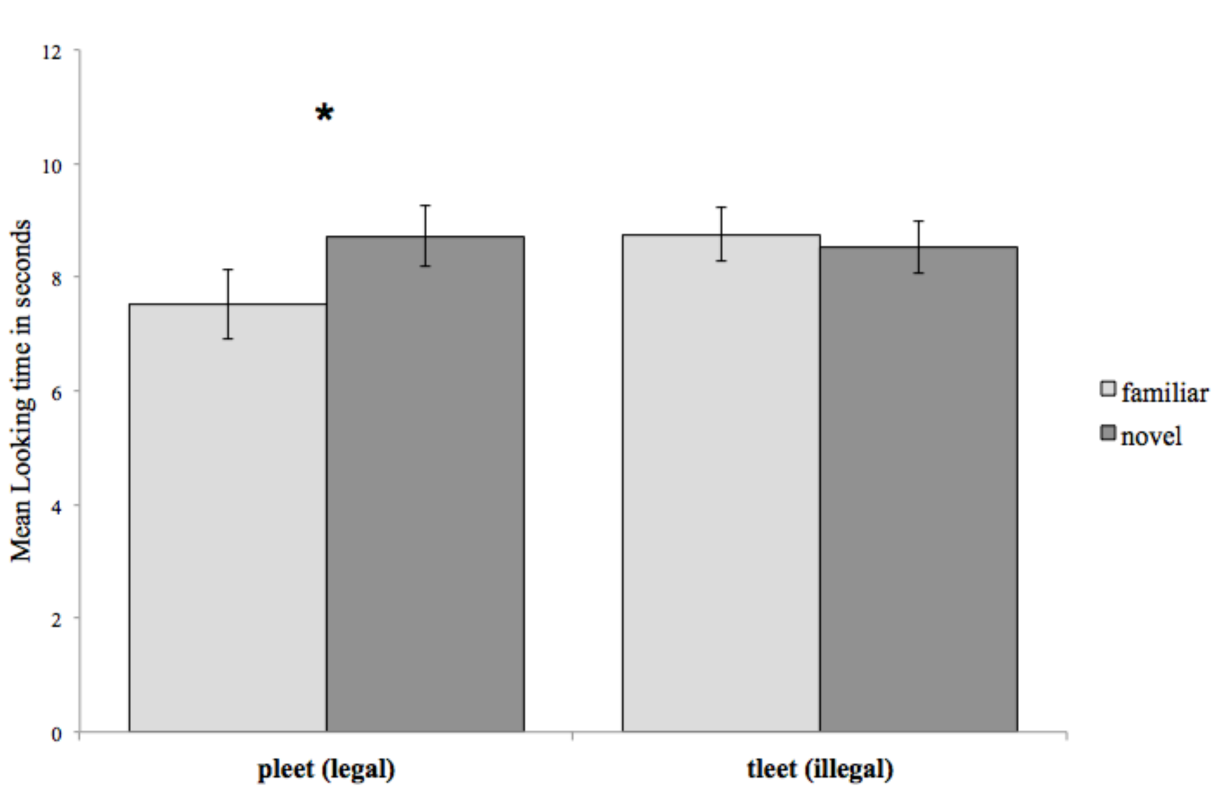
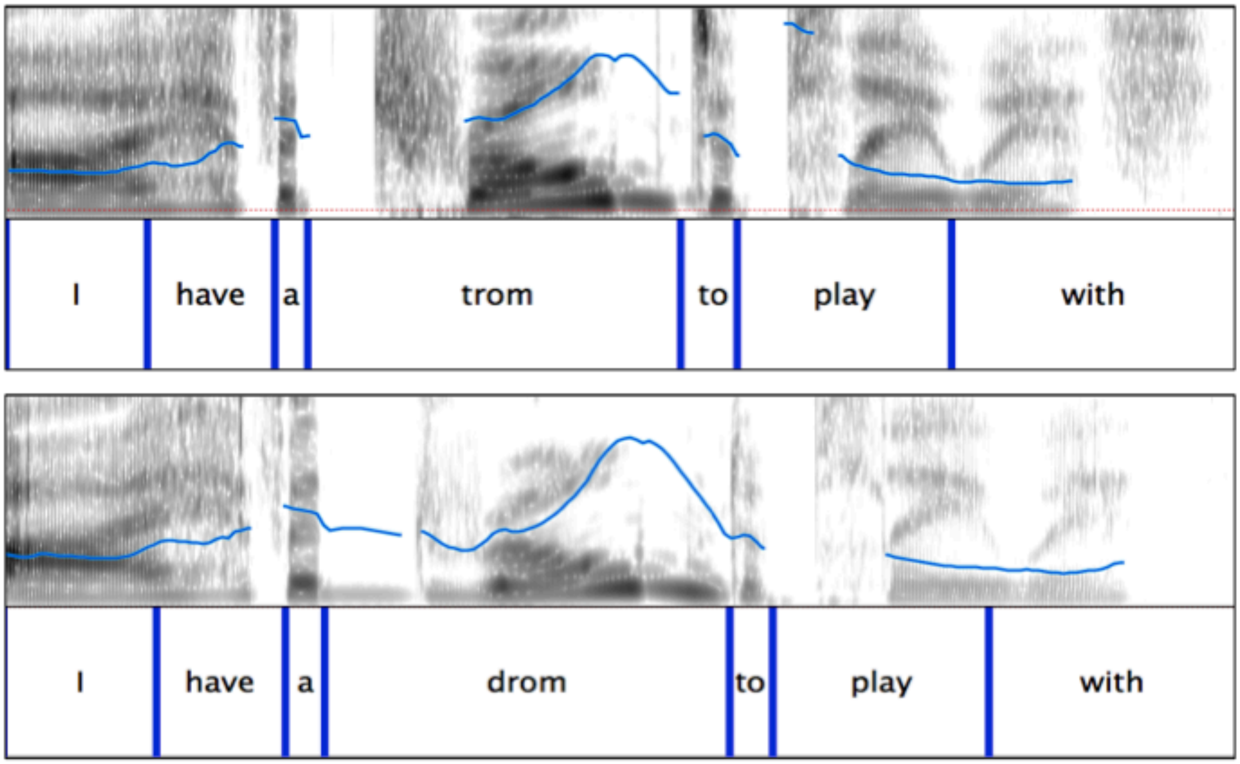
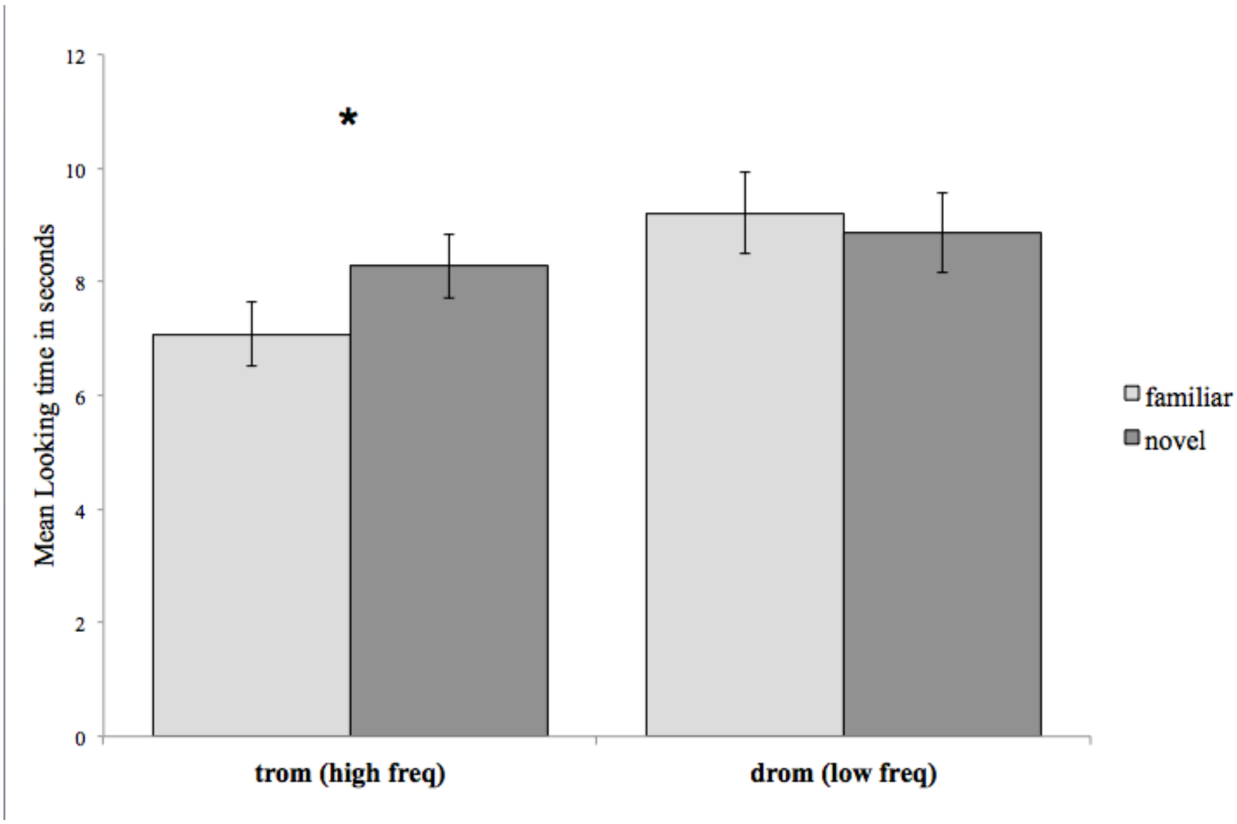
You can take a *pleet/tleet* to school.
I have a *pleet/tleet* in my desk.
I have a *pleet/tleet* to play with.
People often search for *pleet/tleet*.
You can hug a *pleet/tleet*.
Everyone has fun with a *pleet/tleet*.


12
10
8
6
4
2
0
*
Mean Looking time in seconds
pleet (legal)
tleet (illegal)
familiar
novel


I
have
a
trom
to
play
with
I
have
a
drom
to
play
with

You can take a *trom/drom* to school.
I have a *trom/drom* in my desk.
I have a *trom/drom* to play with.
People often search for *trom/drom*.
You can hug a *trom/drom*.
Everyone has fun with a *trom/drom*.


12
10
8
6
4
2
0
*
Mean Looking time in seconds
familiar
novel
trom (high freq)
drom (low freq)

Appendix A

Table 1
Type frequency counts of stop-liquid onset as reported in Archer & Curtin (2011)

Type frequency: adult directed

Cluster	Count (Kucera Francis, 1967[a] & Brown, 1984[b], Coltheart, 1981[c])	Frequency group
pr	295	high
tr	193	
kr	148	
br	119	medium
gr	113	
kl	112	
pl	108	
bl	74	low
dr	64	
gl	55	

[a] Kucera, H. & Francis, W.N. (1967). *Computational Analysis of Present-Day American English.* Brown University Press: Rhode Island.

[b] Brown, G.D.A. (1984). A frequency count of 190,000 words in the London-Lund Corpus of English Conversation. *Behavioral Research Methods Instrumentation and Computers 16,* 502-532.

[c] Coltheart, M. (1981). The MRC Psycholinguistic Database. *Quarterly Journal of Experimental Psychology*, *33*A, 497-505.

Table 2
Token frequency counts of stop-liquid onset as reported in Archer & Curtin (2011)

Token frequency: child directed

Cluster	Count (Brent, 2004[a])	Frequency group
pl	856	high
kl	658	
tr	546	
bl	401	medium
dr	398	
br	372	
gr	359	
kr	289	low
pr	279	
gl	79	

[a] Brent, M. (2004). CHILDES. Retrieved June, 2007, Web site: http://xml.talkbank.org:8888/talkbank/file/CHILDES/Eng-USA/Brent

Table 3
Type frequency counts of ‘a’ + stop-liquid onset in two contexts: within-word and between words (corpus: Kucera-Francis (1967)[a]; database: Coltheart, 1981).

Frequency of within-word and between words: ‘a’ + ‘pl’, ‘tl’, ‘tr’, ‘dr’

Stimuli from exp. 1 & 2	within-word count /əC_1C_2/[1]	between words count /ə + C_1C_2/[2]	Example (within-word, between words)
pleet	11	65	applause, a plant
tleet	2	0	atlas, <none>
trom	8	138	atrophy, a trail
drom	7	47	address, a dream

[a] Kucera, H. & Francis, W.N. (1967). *Computational Analysis of Present-Day American English.*
[b] Coltheart, M. (1981). The MRC Psycholinguistic Database. *Quarterly Journal of Experimental Psychology*, *33*A, 497-505.
[1] Vowel /ə/ denotes the most frequent phonetic production of the determiner ‘a’ in most dialects of English (a+C_1C_2) and as an unstressed initial syllable (a C_1C_2) though it can also be produced as /æ/ (atlas) or /ʌ/ (applause).
[2] “Between words”: Determiner ‘a’ immediately preceding a word with a specific onset (i.e., *pl*, *tl*, *tr*, *dr*). To determine the frequency of ‘a’ before a stop-liquid onset, we counted all words that Kucera-Francis written corpus (1967) identified as nouns. Any noun will often be preceded with the determiner ‘a’. We counted the instances in which a word beginning with *pl*, *tl*, *tr*, and *dr* would be considered a noun.

Appendix B

Number of infants looking longer during the novel trials than familiar trials (test phase).

		Sample size	Number of infants looking longer during novel trials
Experiment 1	*pleet*	24	20
(n = 48)	*tleet*	24	12
Experiment 2	*trom*	24	17
(n = 48)	*drom*	24	10