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Twenty-Four-Month-Olds’ Perception of Word-Medial Onsets and Codas

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ABSTRACT
Recent work has shown that children have detailed phonological representations of consonants at both word-initial and word-final edges. Nonetheless, it remains unclear whether onsets and codas are equally represented by young learners since word edges are isomorphic with syllable edges in this work. The current study sought to explore toddler’s sensitivity to onsets and codas without this overlap. This question is of theoretical interest since many theories of phonology suggest that onsets may be weighted more heavily than codas. We examined English-learning 24-month-olds’ sensitivity to mispronunciations in word-medial onset and coda positions in a word learning task. We predicted that if children’s sensitivity to onsets and codas is positionally constrained, then they should be more tolerant of Coda mispronunciations than onset ones. The results supported this prediction: children were less sensitive to coda mispronunciations than to onset mispronunciations in word-medial position, suggesting positionally driven biases in word processing.

Introduction
A large literature documents adults’ rapid and robust sensitivity to phonological distinctions in word recognition (Magnuson, Dixon, Tanenhaus, & Aslin, 2007; McMurray, Tanenhaus, Aslin, & Spivey, 2003). This sensitivity enables adults to focus on the linguistic dimensions that are critical for distinguishing among highly similar words. For example, this enables adults to discriminate margin from Marvin by attending to a change in the word-medial onset and to discriminate grateful from graceful by attending to a change in the word-medial coda. Despite their well-specified representations of words, adults are also able to accommodate variability in the words produced by different talkers or at different speech rates. For example, after less than a minute of familiarization to an accent which significantly impacts the pronunciation of phonemes, English-speaking adults are able to recognize accented English words produced by Spanish and Chinese speakers (Clarke & Garrett, 2004). Similarly, prior studies show that children are also able to accommodate small acoustic differences due to accent in certain situations (e.g., Schmale, Cristia, & Seidl, 2012). However, these abilities are limited and may rely heavily on lexical knowledge (White & Morgan, 2008), and the exact nature and specificity of infant lexical representations is far from clear. We would ideally like to know if children bring certain phonological biases in encoding words such that while they accommodate some types of mispronunciations, they will not accommodate others.

The primary purpose of this study is to investigate one such area of phonological structure, namely, syllable structure. Specifically, we examine whether young children show an asymmetrical pattern in processing word-medial onsets and codas while learning novel words. This is an important question as many phonological theories, motivated by surveys of language typology,

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suggest such biases exist because, cross-linguistically, languages favor onsets over codas (e.g., Blevins, 1996; Prince & Smolensky, 1993). In support of this idea, evidence from children’s production shows a clear developmental pattern regarding the acquisition of syllable types and positions, suggesting that onsets are acquired earlier than codas (e.g., Demuth, 1995; Levelt, 2012; C. C. Levelt, Schiller, & Levelt, 2000). In addition to the evidence from production, the speech perception literature has demonstrated that pre-literate children show different degrees of phonological awareness of onsets and rhymes (Goswami & Bryant, 1990); this evidence, to a certain degree, can be related to children’s different level of sensitivity to onsets and codas. Even as mature language learners, adults may still find codas to be more difficult to identify than onsets. The asymmetry between onsets and codas may be related to phonologically driven learning biases. Thus, investigation of children’s sensitivity to word-medial onset and coda mispronunciations will help to illuminate the nature of children’s early lexical representations and the presence or absence of positional biases.

Much like adults, researchers have found that infants are able to distinguish small phonetic contrasts from the second half of their first year. For example, Jusczyk and Aslin (1995) showed that even 7.5-month-old infants recognized the difference between cup and tup, indicating that these young infants have a fairly well-specified representation of word-initial onset segments. Subsequent work exploring the level of detail in young children’s phonological representations has similarly found that they are able to distinguish between canonical word forms and mispronounced forms. This sensitivity to mispronunciations has been found for word-initial onset consonants at 12 months (Ballem & Plunkett, 2005; Fennell & Werker, 2003; Mani & Plunkett, 2010; Nazzi, 2005; Swingley, 2005, 2009; White & Morgan, 2008), vowels at 12 months (Mani & Plunkett, 2007, 2010), word-medial onset consonants at 19 months (Swingley, 2003), and word-final coda consonants at 17 months (Levelt, 2012; Swingley, 2005, 2009) for both familiar and novel words.

Nevertheless, up until now, only a few studies have looked at both word-initial onset and word-final coda and these have yielded mixed results. Some studies have shown that children are sensitive to segmental contrasts regardless of the word position (e.g., Nazzi, 2005; Swingley, 2009; Zamuner, 2013). For example, 14–22-month-old (mean age: 17;23) English-speaking children fixated named targets more when hearing correct pronunciations than hearing mispronunciations either when the mispronunciations involved word-initial or word-final position (Swingley, 2009). In a categorization task, 20-month-old French-learning children showed similar sensitivity to phonological distinctions in both word-initial and word-final positions (Nazzi, 2005). In addition, 29-month-old Dutch-learning children in Zamuner (2013)’s study did not show differential perception of segmental contrasts in word-initial and -final positions. In contrast, others studies have found that children are better at identifying differences in word-initial position than in word-final positions (e.g., Altvater-Mackensen & Fikkert, 2010). For example, Altvater-Mackensen and Fikkert (2010) found that 14-month-old Dutch learners showed earlier sensitivity to the stop-fricative contrast in word-initial compared with word-final position in newly learned words. These conflicting results may due to the age differences in the children being tested. Children who showed recognition of differences in both word-initial and word-final positions in the above-mentioned studies were much older and may be at a more mature stage of language development. Indeed, the role of age or developmental stage on the perception of word-initial and word-final consonants has been found in numerous studies. For example, Levelt (2012)’s study demonstrated that 18-, but not 14-month-olds, are sensitive to word-final consonant omission in a novel-word learning task. In the same vein, Zamuner (2006) found negative results for word-final mispronunciations with 11-month-olds, but positive results for some phonological contrasts in this position with 16-month-olds. In summary, these studies revealed that up until 14 months of age, children showed a more developed ability to process contrasts in word-initial positions than in word-final positions.

However, it is noteworthy that the majority of the previous studies mentioned have only focused on mispronunciations in monosyllabic words, in which word edges are isomorphic with syllable edges. It is, however, important to separate out word-edge effects from syllable position effects, which has not been done in any of these studies cited above. This is crucial because we
know that word-edges are both psychologically (because of primacy and recency effects (Capitani, Della Sala, Logie, & Spinnler, 1992)) and phonologically special. For example, 7-month-olds identify words by focusing on the first and last syllables, but ignoring medial syllables (Benavides-Varela & Mehler, 2015). Similarly, adult show better learning of phonotactic regularities at word-edge than at word-medial positions. Specifically, they learned that $C_1$ and $C_2$ came from distinct sets in structures of $C_1VCCVC_2$, where the target consonants were at word-edge positions, but failed to learn this constraint in words of $CVC_1C_2VC$ structure, where the target consonants were in word-medial positions (Endress & Mehler, 2010).

In addition, children’s processing of word-initial and word-final positions is not necessarily a reflection of their ability in encoding onsets and codas, but could be rather a reflection of temporal processing. This is because, in monosyllabic words, onsets always come before codas. Thus, children’s better knowledge of onsets over codas (as suggested in the work previously mentioned from production) can also be interpreted as support for the fact that their interpretation of linguistic units is incremental. However, in word-medial positions, we can avoid such large temporal differences and even place coda constraints before onset ones. For example, in the monosyllabic word cat /kæt/, the word-initial sound /k/ occurs before the word-final sound /t/; however, in the bisyllabic word faithful /feθ.fʊl/, the word-medial onset /f/ occurs after the word-medial coda /θ/. Thus, if children’s representation of segments is incremental, then they should be more sensitive to word-medial codas than word-medial onsets. On the contrary, if children’s knowledge of onsets and codas were influenced by the phonological knowledge rather than a reflection of temporal effect, then we would expect them to be more sensitive to word-medial onsets than codas.

Finally, it should also be noted that acoustic saliency differs as a function of word position. More specifically, in monosyllabic words, word-final consonants are acoustically less salient than word-initial consonants. For example, in English, word-final stops are produced with an unreleased burst (Denes, 1955) while word-initial ones are produced with aspiration. Thus, the asymmetrical perceptual pattern in onset and coda position seen in the literature may be caused by acoustic differences. However, the acoustic advantage of onsets relative to codas may be largely reduced in word-medial position, especially in bisyllabic trochees where the word-medial coda is in the stressed syllable, while the word-medial onset is located in the unstressed syllable.

Thus, for all the above reasons, it is necessary to look at word-medial position in order to explore the question of whether there are phonologically driven positional constraints on word representations. Up until now, only a few studies have examined children’s sensitivity to word-medial consonants at all. For example, Swingley (2003) found that 19-month-old Dutch-learning children showed better recognition of correct pronunciations over mispronunciations when the word-medial consonant was altered in familiar words (where for required lesser attention because it was familiar), however, he only tested children on familiar words with a CVCV structure (with the underscored consonant as the target mispronunciation). Thus, infants were only tested on mispronunciations of word-medial onsets, but not on word-medial codas. Using the Headturn Preference procedure (HPP; Jusczyk & Aslin, 1995), Wang and Seidl (2015) compared infants’ sensitivity to both onsets and codas in word-medial positions. They found that 12-month-olds learned the experimental pattern when the target fricatives were licit in the word-medial onset position, but not in the word-medial coda position. However, by 15 months of age, infants were also able to learn and generalize such patterns for word-medial codas. Similarly, in a recent study, Archer, Zamuner, Engel, Fais, and Curtin (2016) explored English-learning 12- and 20-month-olds’ discrimination of coda consonants in word-medial positions using a habituation paradigm. The results showed that 20-month-olds, but not 12-month-olds, discriminated this contrast for both voiced and voiceless stops. Nevertheless, these studies do not tell us much about how well the information in the onsets and codas are represented while learning novel words, because infants and children often demonstrate less sensitivity to phonological details in words, particularly when they need to simultaneously pay attention to meaning and form (Werker, Fennell, Corcoran, & Stager, 2002).
The secondary goal of the research was to investigate the degree of phonological deviation in children’s ability to process segmental contrasts. Many studies have demonstrated that children are sensitive to the major dimensions of phonological variation, such as voicing, place, and manner, which define phonological features (e.g., Mani & Plunkett, 2010; Miller & Eimas, 1983; White & Morgan, 2008). This knowledge is of particular importance to infants and young children who are faced with the challenging task of building the lexicon of their native language, in which words with minimal phonetic differences may be abundant. For example, as mature language learners, they will have to distinguish between cat and pat, which differ only in the place of articulation (POA) of the first sound. Previous research has found that toddlers in the second year of life have demonstrated sensitivity to even one such featural change in familiar words (Ballem & Plunkett, 2005; Mani & Plunkett, 2010; Swingley & Aslin, 2000, 2002). Despite this seemingly fine-grained sensitivity to featural changes, literature concerning the degree of phonological deviation in children’s word recognition or processing has been inconclusive. Specifically, in some studies, children up to 23 months responded similarly to single-feature and multiple-feature mispronunciations (Bailey & Plunkett, 2002; Swingley & Aslin, 2002). In other studies this was not the case. For example, in White and Morgan (2008) 19-month-olds showed graded sensitivity to the varying degree of phonological mismatch, and this sensitivity can be generalized to a varying combinations of features. These conflicting results may arise from differences in task demands, age at test, as well as the very nature of tasks. In order to add to the existing body of literature on this standing issue, we incorporated another variable, namely 1-feature and 2-feature change from correct pronunciation, in our experimental design.

In summary, the primary goal of the current research was to explore whether there is an asymmetry in children’s representation of word-medial onsets and codas in a word learning task. The secondary goal was to examine whether children’s ability to encode contrasts is affected by the degree of phonological deviation (1-feature vs. 2-feature change). Specifically, using the Preferential Looking paradigm (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987), we tested 24-month-old English-learning children’s response to correct pronunciations (CPs) and mispronunciations to newly learned words in both onset (MP-Onset) and coda (MP-Coda) positions. We varied the degree of phonological deviation such that half of the children received 1-feature change from target labels to the MPs, and the other half received 2-feature changes from the target labels to the MPs. Children’s eye movements in response to stimuli were monitored and analyzed. If children’s word representations were constrained by phonologically driven positional biases, then they should show better recognition of the target object when the label was mispronounced in coda over onset position. With regard to the secondary research question, we predicted that if children are sensitive to the degree of phonological deviation, they should display more sensitivity to MPs that deviate from CPs in two phonological features than to MPs that deviate from CPs in one phonological feature.

**Methods**

**Participants**

Thirty-two healthy full-term monolingual English-learning children (12 females) participated in the study. These children were between the ages of 21.68 and 25.59 months (M = 23.76 months, SD = 0.79). An additional 11 children were tested whose results were not reported for the following reasons: 7 for fussing or crying; 3 for experimenter error; 1 for having looking times with difference scores (Target-Distractor) more than 2.5 standard deviations off the overall mean.

Children were compensated with a book or a toy for their participation. Informed consent was given to the caregivers before testing was carried out. The caregivers were also asked to complete the short form A of the MacArthur-Bates Communicative Developmental Inventory: Level II Vocabulary Checklist (CDI, Fenson et al., 2000) in order to elicit participants’ productive vocabulary.
sizes. The number of words produced by these 32 children ranged from 14 to 100 (\(M = 55.41, SD = 26.24\)).

**Stimuli**

The visual stimuli were digitized pictures of novel objects on a white background, presented on a large screen TV monitor. Pictures were of similar sizes with bright colors. An example stimulus pair is shown in Figure 1.

The auditory stimuli were novel bisyllabic trochees (CVC.CV) composed of English phonemes. These auditory stimuli were produced by a young adult female native speaker of American English in an infant-directed register. The speaker had experience in recording stimuli for previous infant studies. She was informed that all the pseudowords involved were trochaic words with a CVC.CV structure. The stimuli were recorded using a wireless Lavalier microphone (AKG WMS40) in a sound-shielded booth with a Marantz Professional Solid State Recorder (PMD660ENG). The auditory stimuli were digitized at a 44.1 kHz sampling rate and normalized at an amplitude of 75 dB.

The target labels presented to infants in the training trials were: /gæz.bi/, /læz.di/, /dul.mi/, /ruv.mi/, /rin.va/, /din.la/, /lad.vu/, /dim.la/, and /gab.vu/. Each infant was taught two words, one from the Onset-group, and the other from the Coda-group. The word from the Onset-group was mispronounced in the word-medial onset position (MP-Onset; CVC.CV; the underlined segment was mispronounced), and the word from the Coda-group was mispronounced in the word-medial coda position (MP-Coda; CVC.CV, the underlined segment was mispronounced), in other words, they received MP-Onset and MP-Coda test trials for different words. In addition to the mispronunciations (MPs) for the two labels, children also received correct pronunciations (CPs) of the two target labels. For example, the CP and MP-Onset of the target word /gæz.bi/ were /gæz.bi/ and /gæz.mi/, and the CP and MP-Coda of the target word /lad.vu/ were /lad.vu/ and /lag.vu/, respectively. Figure 2 presents an example of experimental design. Since we also wanted to explore whether this effect is more salient when the MPs involved more phonological features, we manipulated the stimuli in this way so that half the participants received MPs whose mispronounced segments deviated from the correct pronunciations in only one phonological feature (1-feature change), and the other half in two phonological features (2-feature change). The number of feature change, duration, amplitude, and maximum pitch of target labels in the CPs, MP-Onset, and MP-Coda Test trials are given in Table 1 and Table 2. Separate One-way ANOVAs were conducted to compare these acoustic measures among the three types of labels. The results showed that there was no systematic difference in the duration, \(F(2, 22) = 2.45, p = .110\); however, we found a significant main effect of Type (CP, MP-Onset, MP-Coda) in the amplitude, \(F(2, 22) = 33.08, p < .001, \eta^2 = .182\), and the maximal pitch, \(F(2, 22) = 46.14, p < .001, \eta^2 = .808\). Post hoc pairwise comparisons with Bonferroni correction (multiplied \(p\)-values by 3) were conducted. The results revealed that MP-Onset and MP-Coda labels were significantly higher in both measures of amplitude, \(t(14) = 6.18, p < .001, t(14) = 8.50, p < .001\), respectively.
and maximal pitch, \( t(14) = 6.77, \ p < .001 \), \( t(14) = 10.48, \ p < .001 \), than CP labels. However, importantly, there was no significant difference between MP-Onset and MP-Coda labels for both the measures of the amplitude, \( t(15) = 0.17, \ p = 1 \), and maximal pitch, \( t(15) = 0.99, \ p = 1 \).

Table 1. Number of feature changes, duration (ms), maximum pitch (Hz), and intensity (dB) of the CPs and MPs for words from the Onset-group.

<table>
<thead>
<tr>
<th>Feature</th>
<th>CPs</th>
<th>MPs-Onset</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Label</td>
<td>Dur (ms)</td>
</tr>
<tr>
<td>1</td>
<td>gaz.bi</td>
<td>612</td>
</tr>
<tr>
<td>1</td>
<td>laz.di</td>
<td>676</td>
</tr>
<tr>
<td>1</td>
<td>dul.mi</td>
<td>546</td>
</tr>
<tr>
<td>1</td>
<td>ruv.ni</td>
<td>577</td>
</tr>
<tr>
<td>2</td>
<td>rin.va</td>
<td>530</td>
</tr>
<tr>
<td>2</td>
<td>din.la</td>
<td>532</td>
</tr>
<tr>
<td>2</td>
<td>lad.vu</td>
<td>621</td>
</tr>
<tr>
<td>2</td>
<td>gab.vu</td>
<td>610</td>
</tr>
</tbody>
</table>

Procedure

Participants were trained and tested using the Preferential Looking Procedure (Golinkoff et al., 1987) in a single-walled sound booth. The participants sat on a caregiver’s lap and watched images projected on the display at eye level. Each caregiver wore darkened sunglasses to avoid looking at the display, and was asked to avoid interfering with their child’s performance. Speech stimuli were presented through a central speaker beneath the display. A camera below the display recorded toddlers’ looking patterns.
The toddlers were taught two novel target words. For each target word, they received 8 trials: 1 Salience trial, 3 Training trials, and 4 Test trials (2 CP trials, and 2 MP trials). Thus, each child received 16 trials (8 trials x 2 words) in total. Salience trials served to reduce the difference in exposure time to the two objects, one of which was presented repeatedly during the Training (the “Target”), while the other (the “Distractor”) only appeared at Test. An attention-getter (smiling baby’s face) appeared preceding each trial to attract toddlers’ attention. When the toddlers looked at the attention-getter, the experimental trials began.

In Salience trials, the Target and the Distractor were shown on the right and the left sides of the screen with no auditory stimulus. During each of the three Training trials, participants saw a picture (Target) shown in the middle of the screen, while listening to the target label, recorded within a carrier sentence. The sentences presented during Training trials were: “Look, it’s the [Target]. The [Target]!” During the four Test trials, the Target and the Distractor were shown simultaneously on the screen, as in Salience trials. The sentences presented in the test trials were, “Where is the [CP]/[MP]? Can you find the [CP]/[MP]?” The Test trials were always played in the order of CP-MP-CP-MP. This is because we expected that the task of representing word-medial segments while learning new words might be challenging for young children, and to have CPs come before MPs might reinforce their learning of these words with a complex syllable structure. Since our primary question of interest was not in comparing CPs to MPs, but rather in exploring potential differences between the two types of MPs (MP-Onset, MP-Coda), we were not concerned about creating biases with this strict ordering.

Speech stimuli began 500 ms after the visual stimuli were shown on the display; the speech stimuli for each trial was 3500 ms in total; the visual stimuli remained on the display for another 1500 ms after the speech stimuli were completed. Thus, each trial was 5.5 s. A total of 32 stimuli orders were created by balancing the target objects, sides, and the location of the mispronunciation (Onset or Coda).

**Coding**

Videos of the participants’ looking patterns to objects on the display were digitized at 30 frames per second and coded offline frame by frame by a highly trained coder using **SuperCoder** software (Hollich, 2008). Participants’ looking directions to the left, right, or away, were coded by a skilled coder. This procedure allowed us to determine the total amount of time and longest looking time children spent looking to the Target and Distractor.

The Test trials were divided into two phases: a pre-naming phase and a post-naming phase. The time window before the onset of the target words in each Test trial was the pre-naming phase. Children’s looking patterns during the pre-naming phase provide a baseline of target preference. In the post-naming phase, following previous research (Swingley & Aslin, 2000), looking time to each object in each Test trial was measured in a time window from 367–2000 ms from the beginning of
the target segment, i.e., the beginning of the fourth segment of CVC.CV (MP-Onset), and the third segment of CVC.CV (MP-Coda). This ensured that any change in the looking pattern occurred as result of the response to the spoken word. For dependent measures, following previous research (Mani & Plunkett, 2008; Swingley, 2009), we calculated the proportion of time that participants looked at the named target picture relative to the total looking time (either at the Target or the Distractor)—Proportion of Target Looking measure (PTL). In addition, we also calculated children’s longest looking time to the Target and Distractor within the same time window. The Proportion of Longest Looking measure (PLL) was calculated by dividing the longest time children spent looking at the Target by the sum of the longest looking to the Target and the Distractor. Given that children were tested with correct pronunciations in both CP-Onset and CP-coda trials, the average CPs were computed over the CP-Onset and CP-Coda, thus resulting in three different types of Test trials (CP, MP-Onset, MP-Coda) in the analyses. Table 3 presents the PTL and PLL measures for these three types of test trials in both the pre-naming and post-naming phases.

Results

A repeated measures ANOVA on PTL with Feature (1-feature change, 2-feature change) as between-subjects factor, Naming (pre-naming, post-naming) and Trial type (CP, MP-Onset, MP-Coda) as within-subjects factors revealed a significant interaction of Naming and Trial type, $F(1.72, 51.46, \text{Huynh-Feldt corrected values}) = 4.96, \ p = .014, \ \eta^2 = .142$. The only factor that approached significance was Naming, $F(1, 51.46, \text{Huynh-Feldt corrected values}) = 2.94, \ p = .097$. However, all other main factors or interactions were not significant, $F_s < 2.62, \ p_s > .116$. To explore the source of the interaction, post hoc paired-samples t-tests were conducted to compare children’s target looking between pre-naming and post-naming phases. Figure 3 presents the effect of Naming using the PTL measure for the CP, MP-Onset, and MP-Coda Test trials. In CP trials, the results showed a significant increase in target looking from the pre-naming to the post-naming phase, $t(31) = 3.31, \ p = .002$ (all reported t-tests were two-tailed). This significant target preference provided evidence that the toddlers learned the novel words used in the experiment. In MP-Coda trials, the PLL was marginally higher in the post-naming phase than in the pre-naming phase, $t(31) = 1.91, \ p = .062$, however, in MP-Onset trials, no significant difference was observed between the pre- and post-naming phases, $t(31) = −1.44, \ p = .161$.

In order to corroborate these results using a different, potentially more sensitive measure, we also conducted a repeated measures ANOVA on the PLL measure with Feature (1-feature change, 2-feature change) as between-subjects factor, Naming (pre-naming, post-naming) and Trial type (CP, MP-Onset, MP-Coda) as within-subjects factors. The results revealed a significant interaction of Naming and Trial type, $F(1.71, 51.26, \text{Huynh-Feldt corrected values}) = 5.99, \ p = .007, \ \eta^2 = .166$. The main factor of Naming was marginally significant, $F(1, 51.26, \text{Huynh-Feldt corrected values}) = 3.09, \ p = .089$. All other main factors or interactions were not significant, $F_s < 2.12, \ p_s > .137$. Post hoc paired-samples t-tests demonstrated that in CP trials, the PLL measure was significantly higher in the post-naming phase than in the pre-naming phase, $t(31) = 3.70, \ p = .001$; In MP-Coda trials, the PLL was marginally higher in the post-naming phase than in the pre-naming phase, $t(31) = 1.91$,
p = .066. However, no significant difference was observed between the pre- and post-naming phases in the MP-Onset trials, \(t(31) = -1.77, p = .086\). Figure 4 presents the effect of naming using the PLL measure.

It should be noted that the effect of naming (the magnitude of change from pre-naming to post-naming) could be influenced by the measures taken at the baseline, such that they determined how much room there was to move from the pre-naming phase to the post-naming phase. In order to address this potential confound, repeated measures ANOVAs on PTL and PLL with Feature (1-feature change, 2-feature change) as between-subjects factor, and Trial type (CP, MP-Onset, MP-Coda) as within-subjects factors were conducted for pre-naming phase. No significant main effects or interactions were found using either PTL, \(F_{s} < .94, p > .382\), or PLL, \(F_{s} < .93, p > .387\).

Taken together, these results suggest that: (1) differences between pre- and post-naming phases following CP and MP-Coda that we found in the previous set of analyses were indeed attributable to the effect of naming; and (2) children recognized the target objects when hearing correctly pronounced labels and labels with mispronounced codas, however, they failed to recognize target objects when hearing labels with mispronounced onsets.

**Discussion**

The primary goal of the current study was to explore syllable positional effects on children’s sensitivity to the mispronunciation of recently learned words. Although a considerable body of research has documented infants’/children’s sensitivity to mispronunciations in both word-initial and word-final positions, no previous study has systematically examined whether children show asymmetrical patterns in recognizing mispronunciations in word-medial onset vs. coda positions. Our study suggests that children show a positional asymmetry while learning novel words that is unrelated to word edge effects. Specifically, children looked longer at the target object when the label was correctly pronounced or was mispronounced in word-medial coda, but failed to do so when the mispronunciation occurred in word-medial onset position. The secondary goal of this research was

* The effect of naming was significant, \(p < .05\).

+ The effect of naming was marginally significant, \(.05 < p < .1\).

Figure 3. Effect of naming in CP, MP-Onset, and MP-Coda trials using PTL measure. Error bars indicate standard error.
to examine the degree of phonological deviation in children’s ability to process segmental contrasts. Previous research examining this question has yielded mixed results. Our study shows that children are equally sensitive to MPs that deviate from CPs in one phonological feature and two phonological features in lexical processing.

With respect to our primary research question, the results are consistent with prior studies showing an asymmetrical learning of phonotactic patterns restricted to either word-medial onset or coda position in younger infants (Wang & Seidl, 2015). While this finding, at first glance, seems to contrast with Swingley (2009) and Nazzi (2005)’s studies reporting a symmetrical representation of word-edge onsets and codas in children at younger ages, there is of course a crucial difference: word edges are special. In addition, given the task of word learning is cognitively more demanding than the task of familiar word recognition, it is possible that children’s symmetrical sensitivity to word-initial and -final mispronunciations in Nazzi (2005) and Swingley (2009)’s work is the result of a ceiling effect. However, while from the second year on children are able to represent detailed phonological information correctly in both word-initial and word-final positions of familiar words, when exposed to a more challenging word learning task in which mispronunciations occur in word-medial positions, children show onset biases. These biases may appear due to the greater cognitive demands of complex syllable structure in word learning or may simply reflect the lesser salience of word-medial positions, either way, it is clear that not all positions may be treated equally.

One may argue that children’s better representation of sounds in onset position over coda position in our study might be due to the fact that onsets are acoustically more salient than codas. However, this is less likely in word-medial position in English trochees in which codas appear in the stressed syllable, and onsets in the unstressed syllable. Indeed, in a recent study, Wang and Seidl (2015) compared the acoustics of word-medial onsets and codas in bisyllabic trochees with the structure CVC.CVC, and found that the sounds in the word-medial codas were greater in both amplitude and F0 than the word-medial onsets. Thus, the acoustic advantage of onsets over codas

* The effect of naming was significant, $p < .05$.

+ The effect of naming was marginally significant, $.05 < p < .1$.

Figure 4. Effect of naming in CP, MP-Onset, and MP-Coda trials using PLL measure. Error bars indicate standard error. Error bars indicate standard error.
that is typical at word-edges disappears in these word-medial positions, allowing us to disentangle positional effects with acoustic saliency.

While disentangling the word-edge effects, sequence effects, as well as acoustic saliency of onsets and codas, this study reveals for the first time children’s asymmetrical sensitivity to onsets and codas in the word-medial position in newly learned words. One possible interpretation of this processing advantage of onset over coda position is that children may have built more detailed phonological representations of sounds appearing in onset position. Another possibility is that children may have built detailed phonological representations of sounds in both onset and coda positions, however, they are more willing to accommodate a change in coda position than in onset position, such that mispronunciations in onset, but not in coda position, hinder word recognition. Interestingly, the asymmetrical processing of word-medial onsets and codas may account for why the world’s languages are the way they are. Specifically, despite the range of syllable structures present in the languages of the world, typological investigations have demonstrated that CV is the only syllable type that is always licit across the world languages. Given the complexity of language structures to be learned by children, a potential role of onset biases are to direct learners’ attention to the kind of information that is needed to further develop their perceptual capacity.

With respect to our secondary research questions, we do not find graded sensitivity to the degree of phonological deviation on word recognition. This result is in line with Bailey and Plunkett (2002) and Swingley and Aslin (2002)’s findings that children up to 23 months responded similarly to single-feature and multiple-feature mispronunciations. However, our results differ from White and Morgan (2008)’s findings that 19-month-olds showed linearly graded sensitivity to mispronunciations involving one, two and three phonological features. Specifically, children showed significant increases in looking toward the familiar object in the correct and one-feature conditions, but not in two- or three-feature conditions. The discrepancies between our studies may be due to the referential status of the visual competitors. Specifically, they presented children with a familiar and an unfamiliar object. In contrast, children were presented with novel objects and novel labels in our study. It is also likely that since the children in our study were older, their phonological representation of newly learned words is more detailed. Finally, another possibility is that the differences in the feature changes involved in the two studies result in different magnitudes of acoustic-phonetic mismatch; however, only future studies with systematic investigations can tease these explanations apart.

Last but not least, this study adds to the existing body of literature explaining characteristics of children’s early speech production. When children begin to produce meaningful words, coda consonants are often omitted (e.g., Altvater-Mackensen & Fikkert, 2010; Demuth & Fee, 1995) and CV syllables are acquired earlier than CVC syllables in production (Levelt et al., 2000). Recent experimental evidence and theoretical models claim that children use the same lexical representation for speech perception and production (Altvater-Mackensen & Fikkert, 2010; Levelt et al., 1999), thus, the coda omission and later acquisition of CVC syllables as opposed to CV syllables may be the consequence of children’s better sensitivity to onset over coda position in their lexical representations. Consequently, we may also predict that word-medial onsets will be produced earlier than word-medial codas in children’s output in a way driven by the asymmetrical nature of their phonological representations of sounds in these two syllable positions.

The current study is limited in several respects. First, a potential confound which may impact children’s sensitivity to word-medial onsets and codas is that in word-medial positions, codas are often undergo regressive assimilation to the place and voicing features of their following consonants. In contrast, word-medial onsets are less vulnerable to such changes. Thus, it is possible that children’s lesser sensitivity to coda mispronunciations may due to the fact that codas simply allow for more changes in the input. Second, as we noted earlier, codas were always in stressed syllables, while onsets were always in unstressed syllables. Thus, given that onsets were located at the locus of the change to the second syllable and as well as a change in stress, it is possible that these facts may make the onset easier to notice than coda, resulting in children’s higher sensitivity to onsets than
codas. Unfortunately, current study is not able to address this issue. It would be thus interesting for future work to replicate the present study with other types of word forms such that the coda patterns are in the unstressed syllable and the onset patterns in the stressed syllable in order to examine possible interactions between syllable position and word stress. In addition, this confound could also be eliminated by examining trisyllabic or polysyllabic words with the target onset and coda restricted at the transition of two syllables with relatively equal stress.4 Despite the above-mentioned caveats, we have demonstrated that 24-month-old English-learning children have an asymmetrical sensitivity to word-medial onsets and codas, indicating a potential role of phonological biases in children’s word processing. The asymmetrical patterns that we see in speech perception may also predict children’s production patterns during the course of language acquisition. In addition, the research provides evidence that by the age of 24 months, children have very sophisticated phonological knowledge in words such that minimal phonetic deviation in onset position may affect word recognition.

Notes

1. Although we cannot be sure how infants in our study have interpreted the stimuli, we think it is more likely that they have interpreted them as bisyllabic trochees as it is a more common pattern in English. With regard to how children syllabify the stimuli, we think it is more likely they interpreted the stimuli as CVC. CVC, due to the effect of Weight-Stress Principle and Maximal Onset Principle on syllabification (e.g., Hayes, 1995; Kahn, 1976). In addition, most of these consonant-consonant sequences in the word-medial position, e.g., zm, zg, vd, violate the phonotactic constraints for being a consonant cluster within one syllable position.

2. However, these differences may be less likely to affect the results. Indeed our results go in the opposite direction from the acoustic analyses: children show better recognition of target labels in CP trials than in MP trials. We suspect that the different acoustic measurements between CPs and MPs may due to the fact that the speaker emphasized the MPs because these were relatively new labels compared to the CPs. Crucially, however, MP-onset and MP-coda measures were not distinct prosodically.

3. We also evaluated the possible role of children’s vocabulary size on their representation of segments in word-medial onset and coda positions. The expressive vocabulary size of these 32 children ranged from 14–100 (M = 55.41, SD = 26.24), as calculated from parental CDI reports. Vocabulary size was strongly correlated with children’s age, r = 0.453, p = .009. However, we did not find any correlation between children’s vocabulary size and the effect of naming in any of the Test trials for either PTL measure (r/s < .165, ps > 0.368) or PLL measure (r/s < 0.187, ps > 0.306). These results are consistent with previous findings showing no evidence of a relationship between vocabulary size and infants’ sensitivity to mispronunciations (Ballem & Plunkett, 2005; Swingley, 2009).

4. We thank our anonymous reviewers for suggestions related to this discussion.

References


