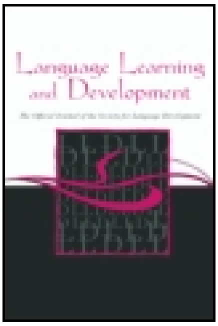


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# Asymmetries in Early Word Recognition: The Case of Stops and Fricatives

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# Asymmetries in Early Word Recognition: The Case of Stops and Fricatives

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Toddlers' discrimination of native phonemic contrasts is generally unproblematic. Yet using those native contrasts in word learning and word recognition can be more challenging. In this article, we investigate perceptual versus phonological explanations for asymmetrical patterns found in early word recognition. We systematically investigated the use of two types of phonological contrasts in toddlers' word recognition: manner and place of articulation. Ninety-six Dutch 18- and 25-month-olds were tested in a mispronunciation detection task. We show that 18-month-olds are sensitive to changes from fricative to stop, but not from stop to fricative, while 25-month-olds are able to detect changes in both directions. Confirming earlier findings on perceptual asymmetries, we find a similar asymmetrical pattern for mispronunciations involving labials and coronals at 18 months of age. We argue that the observed asymmetries reflect the nature of phonological representations used for word recognition at different stages of development.

## INTRODUCTION

During the first year of life, infants start learning the sound contrasts that are important in their native language (Werker & Tees, 1999; Kuhl et al., 2008) and how these sounds pattern in words (Jusczyk & Aslin, 1995). Given that infants can build on this knowledge when they acquire their first words, one could assume that it is a relatively straightforward task to learn the sound structure of words and to store their phonological form in the mental lexicon. Nevertheless, results from perception studies in the past decades show that recognizing sound contrasts in words is more

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challenging than either sound discrimination or pattern recognition, and these sometimes conflicting results have led to different assumptions regarding the nature of children's phonological forms.

In this article, we explore the nature of children's phonological representations in two experiments with Dutch-learning toddlers, investigating the perception of manner and place of articulation contrasts in familiar words. We will argue that these contrasts are a suitable test case to differentiate between different explanations for perceptual patterns found in previous studies on early word learning and early word recognition.

Early word learning has been studied in a series of well-known "Switch"-studies (e.g., Stager & Werker, 1997; Pater, Stager, & Werker, 2004). Werker and colleagues showed that 14-month-olds have difficulties learning two similar-sounding words that contrast only in place of articulation of the initial consonant, for example 'bih' and 'dih' or 'bin' and 'din'. Since children are able to distinguish between the same word forms in a straightforward discrimination task, the results allow for at least two different interpretations: either children fail to encode the relevant detail in their lexical representations, or they are not able to use all stored detail in a word recognition task with newly learned words. The first interpretation relies on the argument that children's initial representations are not adult-like (e.g., Ferguson & Farwell, 1975; Fikkert, 2010). The second interpretation stresses high task demands as a source of children's poor performance (e.g., Werker & Curtin, 2005).

In a number of follow-up studies, Fennell and colleagues showed that 14-month-olds are indeed able to learn two similar-sounding words if task demands are lowered (Yoshida, Fennell, Swingley, & Werker, 2009; Fennell & Waxman, 2010; Fennell, 2012). These findings strengthen the argument that the source of children's failure in earlier word-learning experiments is the task demand rather than the lack of detail in phonological representations. Additional support for this view comes from studies investigating children's ability to detect mispronunciations in familiar words. This is an arguably less demanding task than learning two similar-sounding new words. Indeed, 12- and 14-month-olds are able to detect changes as small as a one-feature mispronunciation in familiar words (Swingley & Aslin, 2002; Swingley, 2009; Mani & Plunkett, 2010).

However, most previous studies did not take the direction in which a particular contrast is altered into account, even though several studies have shown that not all phonological contrasts are used to the same extent in word recognition. Most obviously this is the case in nonnative speech perception (e.g., Best, McRoberts, & Goodell, 2001), but we argue that it also holds for children's native speech comprehension. For instance, consonantal information has been argued to be more important for word identification than vocalic information (e.g., Nazzi, 2005; Nazzi, Floccia, Moquet, & Butler, 2009; Havy & Nazzi, 2009; but see Mani & Plunkett, 2010). Even within the class of vowels, different phonological contrasts are not discriminated equally well (e.g., Polka & Bohn, 2003). These findings are an important part of the rational for the current study: given these differences, it is important to study asymmetries in early word recognition in order to gain insights into the type of phonological detail that might cause problems in early word learning and word recognition. Before discussing design and predictions of our study in more detail, we will review previous studies that potentially inform us about differences in infants' use of phonological detail during phoneme discrimination, word learning and (familiar) word recognition.

## Phonological Detail in Infant Phoneme Discrimination

In order to be able to use phonological detail in word learning and to subsequently detect changes or mispronunciations in a word, the child has to be able to perceive the relevant sound contrast. The predominant view on infant speech perception is that babies are born as ‘universal’ listeners, who are able to perceive all sound contrasts that are used in the languages of the world, and that they become ‘native’ listeners, who are only sensitive to sound contrasts relevant in the native language, in the course of the first year of life (Werker & Tees, 1999).

However, not all sound contrasts follow the same developmental path. First, infants may keep their ability to discriminate nonnative sound contrasts if they are unlikely to be perceived phonemically, that is, if they are very different from any native sound contrast or if they can be assimilated into distinct native phoneme categories (Best, McRoberts, LaFleur, & Silver-Isenstadt, 1995). Second, infants do not merely lose sensitivity to nonnative sound contrasts over time, but they also become better in discriminating certain native sound contrasts (Kuhl et al., 2006). Specific sound contrasts are less discriminable for younger infants. For instance, the discrimination of the (native) fricatives /f/, /ʃ/ and /θ/ is difficult for English babies (Eilers, Wilson, & Moore, 1977), and they have more difficulty discriminating differences in voicing for negative than for positive voice onset times (Aslin, Pisoni, Henessy, & Perey, 1981).

Next to acoustic salience, frequency has been argued to play a role in the formation of phonetic categories. Anderson, Morgan and White (2003) found that while 6.5-month-old English babies discriminate both the coronal Hindi contrast /ʈ/-/t/ and the dorsal Salish contrast /k’/-/q’/, 8.5-month-olds still discriminate the dorsal contrast but perform at chance for the coronal contrast. The authors argue that the frequent exposure to coronals in English leads to an earlier attunement for coronal as opposed to dorsal sounds. These findings have been corroborated by Narayan, Werker, and Beddor (2010). They tested Filipino and English learning infants on the nasal place of articulation contrast /ŋa/-/na/. This is a less-salient contrast from an acoustic perspective, and initially neither the English-learning nor the Filipino-learning children reliably discriminate between the two places of articulation. Although coronal and dorsal nasals are phonemic in both languages, English allows dorsal nasals only in syllable-final position therewith severely restricting their frequency. Results show that while Filipino infants have learned to discriminate the contrast at the end of the first year of life, English infants still have difficulties to discriminate it at this age. Similarly, Pons, Albareda-Castellot and Sebastián-Gallés (2012) show that asymmetries in Catalan- and Spanish-learning infants’ perception of the /e/-/i/ contrast are biased by acoustic discriminability at 4 and 6 months of age, while discrimination is influenced by the frequency of the sounds at 12 months of age.

Most importantly for the purpose of this article, infants do not only discriminate some contrasts better than others but they also show directional asymmetries. These asymmetries have been documented best for vowels. For instance, Kuhl, Williams, Lacerda, Stevens, and Lindblom (1992) showed that infants are better able to discriminate within-category contrasts when being exposed to a less typical exemplar of the category first (compared with being exposed to a prototypical exemplar first). Kuhl and colleagues therefore suggest that prototypical native sounds act as perceptual magnets making it more difficult to discriminate them from other sounds falling in the same native sound category. Subsequent studies by Polka and Bohn (1996, 2003, 2011) show that asymmetries in vowel perception apply to a wide range of vowel contrasts including nonnative sound contrasts. Since infants tend to better detect changes from more central to more peripheral vowels in the F1/F2 vowel space than vice versa, Polka and Bohn suggest that peripheral vowels act as referent to establish phoneme categories. Schwartz, Abry, Boë, Ménard, and Vallée (2005) extend this account to incorporate findings that lip-rounding (change in F3) also contributes to perceptual asymmetries (see Best & Faber, 2000; Polka & Bohn, 2011). They propose that the more focal vowel (i.e., the vowel in which two neighboring formants are closer to each other) acts as a referent in perception. Taken together, these studies suggest that perceptually salient vowels serve as anchors in perception which allow infants to establish a system of contrast.

Note that despite this extensive work on asymmetries in vowel perception, there are only few studies reporting directional asymmetries in infants' consonant discrimination. To our knowledge only two studies report perceptual asymmetries between two *native* consonant categories: Kuhl et al. (2006) report that English and Japanese learning infants in general are better able to discriminate /la/ from /ra/ than vice versa (even though the contrast is phonemic in English but not in Japanese). Dijkstra and Fikkert (2010) find that Dutch 6-month-olds better detect a change from 'paan' to 'taan' than vice versa.

Taken together, research on infants' perception of sound contrasts suggests that not all phoneme contrasts are acquired at the same time and rate (Anderson, Morgan, & White, 2003; Narayan et al., 2010) and that the direction in which a contrast is tested might determine if infants succeed in discriminating two sounds or not (Polka & Bohn, 2003, 2011). These perceptual asymmetries might influence infants' ability to use phonological detail in later word learning (see Mugitani et al., 2009, for a similar argument).

## Phonological Detail in Word Learning

The particular phonological contrast involved arguably influences the successful recognition of newly learned, minimally different words. The most well-documented perceptual effects of different contrasts are the effects of different types of vowels and effects of vowels versus consonants.

Curtin, Fennell, and Escudero (2009) investigated 15-month-olds' ability to detect different types of vowel changes in newly learned words. Infants were tested using the minimal pairs 'deet' and 'doot' (a change in vowel backness and rounding), 'deet' and 'dit' (a change in laxness and height), and 'dit' and 'doot' (a change in height, backness and rounding). Results show that infants could only distinguish between 'deet' and 'dit', but none of the other vowel contrasts. Curtin et al. assume that changes in vowel height are more accessible to infants than changes in backness or roundedness and argue that infants initially only use the most salient acoustic information during word learning. Because the change in vowel height is most salient in the contrast between /i/ and /ɪ/, infants only succeed to distinguish between 'dit' and 'deet' (see also Mani, Coleman, & Plunkett, 2008, for similar findings with familiar words and older children in a mispronunciation detection task).

Using a different task design, Mani and Plunkett (2008a) found that 14-month-olds pay sufficient attention to phonological detail during word learning to be able to detect mispronunciations in the vowel of a newly learned word later on. The novel words in this study were 'padge' and 'mot' which were mispronounced as 'poudge' and 'mit', that is, with a change in height, roundedness and backness. The results show that 14-month-olds can detect a change from /æ/ to /aʊ/ and from /ɔ/ to /ɪ/. As these vowel changes involve a rather large distance in vowel height, the results do not contradict Curtin et al.'s (2009) conclusions.

Nazzi and colleagues provide more evidence that children might give differential weight to different phonological contrasts when learning new words. Using a name-based categorization procedure with newly acquainted labels and objects, they found that French 20-month-olds can successfully learn two words differing in place of articulation of the initial consonant, be it a plosive as in /pize/ versus /tize/ (Nazzi, 2005) or a fricative as in /fepod/ versus /ʃepod/ (Nazzi & New, 2007), or two words differing in the voicing of the initial consonant, as in /pod/ versus /bod/ (Nazzi & Bertoncini, 2009). However, the children did not succeed with two words differing in vocalic features, as in /duk/ versus /dok/ (Nazzi, 2005). Similarly, Havy and Nazzi (2009) show that French 16-month-olds are able to learn two words differing in a consonantal feature, but not two words differing in a vocalic feature. Note that the consonantal contrast always involved the place or voicing of an initial stop consonant in this study, while the vowel contrast involved place and height of different classes of vowels. These results are all congruent with the view that consonantal information is more important for lexical learning than vocalic information (Nespor, Pena, & Mehler, 2003). Following this assumption, Nazzi, Floccia et al. (2009) pitted children's use of vocalic and consonantal information against each other. They show that French and English 30-month-olds are more likely to neglect a vocalic feature than to neglect a consonantal feature when they have to match a target object to one of two other objects whose label either differs in the vowel or in the consonant.

The above-mentioned studies suggest that some vocalic features might be more salient during early word learning than others (Curtin et al., 2009) and that consonantal changes might be more reliably detected than vocalic changes (e.g., Havy & Nazzi, 2009). On the other hand, infants' use of different consonantal information in a specific word position does not seem to differ in word learning tasks. Note, however, that infants show different sensitivity to consonant contrasts in stressed compared to unstressed position. For example, Archer, Ference, and Curtin (2012) find that English learning 14-month-olds can detect a switch between /b/ and /d/ in a word learning task if the change occurs in the onset of a stressed syllable, but not if the change occurs in the onset of an unstressed syllable. Acoustic analysis revealed that the F2 difference between /b/ and /d/ is enhanced in stressed position, probably making the contrast more salient and easier to use for infants.

Yet the reported studies did not test whether children were more sensitive to changes in a specific direction, that is, whether there were potential asymmetries in infants' sensitivity to phonological detail. Although the studies sometimes employed both directions of the phonological contrast, most did not specifically investigate possible *directional* effects. However, Nazzi and colleagues report variable performance for different word pairs (Havy & Nazzi, 2009; Nazzi, Floccia et al., 2009; Nazzi & Bertoncini, 2009).

So far, only few word-learning studies have systematically investigated directional effects (with consonants) in more detail. Fikkert (2010) tested 17-month-old Dutch infants in a single-object variant of the switch task on the original 'bin'-'din' contrast that Stager and Werker (1997) also used. She found that infants are able to recognize changes in the onset of newly learned words if a labial stop /b/ is replaced by a coronal stop /d/, but they fail to detect a change from coronal to labial. Thus, although the overall results were similar to previous findings in that 17-month-olds are able to distinguish two similar-sounding words, the effect was bound to a specific direction. This finding is corroborated by recent results of Fennell, Van der Feest and Spring (2010, 2013) showing that analyses of new and previously reported Switch-data with English 14-month-olds reveal similar asymmetries in infants' detection of a change from /bɪn/ to /dɪn/, but not vice versa.

A similar asymmetry was found by Altvater-Mackensen and Fikkert (2010) investigating the perception of stops and fricatives in early word learning. They also used the Switch-procedure, but the words in their study differed in manner of articulation of the first consonant, which was either a labial voiceless stop /p/ or a labial voiceless fricative /f/. The results show that Dutch 14-month-olds are able to detect changes from fricative to stop in initial position of newly learned words but fail to dishabituate if the change is from stop to fricative. In a control condition using a checkerboard pattern instead of an object as visual stimulus, Altvater-Mackensen and Fikkert show that the infants were perfectly able to detect a change from stop to fricative in a straightforward discrimination task. This makes it unlikely that the infants could not perceptually discriminate the two sounds. Instead, the authors argue that manner of articulation information is only reliably encoded for fricatives but not for stops in early lexical representations and that therefore only changes of fricatives are detected (see Fikkert, 2010, for a similar argument with respect to the labial-coronal distinction). We will come back to this point when discussing the design of the current study.

The above-reported studies all investigated young children's sensitivity to different contrasts in tasks involving newly learned words. Our current study aimed to explore children's performance with words learned under natural circumstances, building on previous findings on toddlers' sensitivity to mispronunciations in familiar words that did not take possible perceptual asymmetries into account.

## Phonological Detail in the Recognition of Familiar Words

Most studies testing sensitivity to phonological detail in familiar words find that toddlers are able to spot even subtle one-feature mispronunciations suggesting detailed knowledge about the phonological makeup of words (Swingley & Aslin, 2000, and subsequent studies). It has been argued that lexical specificity increases as a result of familiarity with the word (Barton, 1980; Metsala, 1999) and the need to distinguish similar sounding words in the child's lexicon as it becomes larger and contains more phonological neighbors (Charles-Luce & Luce, 1990; Metsala, 1999; Walley, 2005). Bailey and Plunkett (2002) specifically examined whether 18- and 24-month-olds have less access to phonological detail in recently learned words than in familiar words and whether vocabulary size has any influence on toddlers' performance in a mispronunciation task. They found that both age groups were able to detect variegated one- and two-feature mispronunciations in voicing, place and manner of articulation of the initial consonant. Although they performed less well on some of the recently learned words, there was no main effect of familiarity with the word. The number of neighbors in the lexicon did also not modulate toddlers' sensitivity to mispronunciations suggesting that the use of phonological detail is neither bound to word familiarity nor to vocabulary size. Additionally, Bailey and Plunkett report no difference between small one-feature and larger two-feature mispronunciations suggesting that word recognition is equally disrupted by different degrees of consonantal changes.

This last finding is in contrast to results from White and Morgan (2008), who used a version of the mispronunciation detection paradigm where the distractor object is always an unknown object, and thus a mispronounced word could potentially be a new label for this new object. White and Morgan showed that 19-month-olds are sensitive to the degree of mispronunciations in terms of phonological features (see also Altvater-Mackensen & Mani, 2011, 2013). The larger the feature distance between correctly and mispronounced word, the more toddlers' word recognition is disrupted by the mispronunciation, and the more likely they were to consider the unknown distractor object to be the target. This holds regardless of the types of features involved in the mispronunciation. White and Morgan (2008) find similar additive effects of feature changes for voicing, manner and place of articulation changes. However, both results—the equal impact of different features on word recognition as well as the linear additive effect of feature changes—have been put into question by recent findings of Mani and Plunkett (2010, 2011a).

Replicating the original White and Morgan (2008) study using vowel instead of consonant mispronunciations, Mani and Plunkett (2011a) investigated 18- and 24-month-olds' sensitivity to one-, two- and three-feature mispronunciations. They found that 18-month-olds' sensitivity is not modulated by the size of the mispronunciation. They spot mispronunciations equally well when they differ from the correct pronunciation by one, two, or three features. However, 24-month-olds show differences in sensitivity: the mispronunciation effect is larger for two- and three-feature mispronunciations than for one-feature mispronunciations. Yet, the effect is not linear in terms of phonological features as found in White and Morgan (2008) for consonantal mispronunciations. The size of the mispronunciation effect rather seems to be modulated by the acoustic distance between correctly and mispronounced word. Mani and Plunkett (2011a) put forward that 24-month-olds are using sub-phonemic detail during word recognition, and that this detail may be best described in terms of acoustic properties. The authors also suggest that 18-month-olds do not yet use sub-segmental (vowel) detail given that they did not show any differences in sensitivity depending on the degree of mispronunciation.

Apart from the size of the mispronunciation, the type of mispronunciation might also influence infants' sensitivity. White and Morgan (2008), in one of the few studies comparing different types of consonant mispronunciations with each other, did not find any differences in toddlers' sensitivity to voicing, place and manner of articulation features. In contrast, Mani and Plunkett (2010) show that not all mispronunciations are detected equally well. They tested 12-month-olds' sensitivity to (word-initial) one-feature consonantal mispronunciations in voicing, manner, and place of articulation and to (word-medial) one-feature vocalic mispronunciations in roundedness, height, and backness of well-known words. While the infants were sensitive to changes in manner and place of articulation of the initial consonant, they did not spot mispronunciations in voicing. Vowel changes, on the other hand, were all detected equally well (but see Mani et al. 2008, for limited use of roundedness information in a similar task with 18-month-olds). Interestingly, vowel and consonant changes were equally disruptive for word recognition. This suggests that although vowels and consonants might have a different status for word learning (Havy & Nazzi, 2009) and might be weighted differently when pitted against each other (Nazzi, Floccia et al., 2009), there is no asymmetry in the use of vocalic versus consonantal detail during recognition of familiar words.

Mani and Plunkett's (2010) finding that voicing information is not reliably used during word recognition is in line with findings of Van der Feest (2007) and Van der Feest and Fikkert (2005, 2013). In the first studies that systematically investigated directional effects in toddlers' sensitivity to mispronunciations, they report that 20-month-old Dutch-learning children show no sensitivity to voicing mispronunciations of the initial consonant of familiar words. Only Dutch 24-month-olds are able to detect mispronunciations that involve voicing features, but the mispronunciation effect is asymmetric: changes from unvoiced unaspirated stops to (pre-)voiced stops are detected, but not vice versa; for example, 'boes' is not accepted for *poes* ('cat') but 'pal' for *bal* ('ball') is accepted. A similar asymmetry is observed for 20- and 24-month-olds' ability to detect mispronunciations in place of articulation: the toddlers accept 'peen' as a possible pronunciation of *teen* ('toe'), but not 'toes' for *poes* ('cat'); that is, they detect word-initial mispronunciations that involve a change from labial to coronal, but not vice versa. Van der Feest (2007) and Van der Feest and Fikkert (2005; 2013) argue that the asymmetrical findings are a consequence of infants' initial failure to represent every detail in their lexical representations.

Taken together, results from previous studies on familiar word recognition suggest that children might not have equal access to all phonological detail causing asymmetric effects in word learning and word recognition. This seems to contradict results of Swingley and Aslin (2000, 2002) and subsequent studies, finding that children have detailed knowledge about the phonological make-up of (familiar and recently learned) words. These studies used different types of mispronunciations, but they do not report any asymmetries. However, the only way for asymmetries to show up would have been in an item analysis, which may not be powerful enough in studies not designed to systematically manipulate the *direction* of feature change.

## Overview of the Experiments

In the current experiments, we address the question of children's use of phonological detail in word recognition and investigate the nature of early representations of words by systematically investigating manner of articulation features. We particularly focus on the contrast between stops and fricatives in a word recognition task. This contrast is understudied: only two studies to date have specifically investigated potential *differences* in the use of manner of articulation detail in word learning at 14 months of age (Altvater-Mackensen & Fikkert, 2010) and preschoolers' familiar word recognition (Cole, 1981). Yet this less-studied contrast is particularly suitable to disentangle different accounts of the use of phonological detail. The perception of manner of articulation contrasts is generally unproblematic and much more robust than the perception of place of articulation or voicing contrasts (Benki, 2003; Cole, Jakimik, & Cooper, 1978; Cole, 1981). This reduces the likelihood that perceptual confusion heightens task demands and interferes with word recognition. The acoustic characteristics of stops and fricatives make misperception less likely than is the case for place of articulation and voicing differences. It provides a stronger test case for directional effects than the labial-coronal contrast, which has been extensively studied before (see our general discussion for more details).

If the directional asymmetries in sensitivity to phonological detail observed by Fikkert and colleagues (Fikkert, 2010; Altvater-Mackensen & Fikkert, 2010; Van der Feest & Fikkert, 2005, 2013) are indeed grounded in the nature of early lexical representations, we predict similar asymmetries in sensitivity to manner of articulation features. Considering the phonetic and phonological characteristics of manner of articulation features, and more specifically the contrast between stops and fricatives that we investigate in the current study, we predict that toddlers will be more sensitive to mispronunciations of fricatives than to mispronunciations of stops.

Our predictions are based on the asymmetric findings in Altvater-Mackensen and Fikkert (2010), as well as on the assumption that fricatives are linguistically more "marked" than stops because of their phonetic and phonological characteristics (Trubetzkoy, 1939; Chomsky & Halle, 1968) and that fricatives will therefore have to be specified in lexical representations (Jakobson, 1941). We discuss issues of markedness and the implications of these assumptions for early lexical representations and word recognition in further detail in the general discussion. For now, our main hypothesis will be that mismatches in phonological detail related to fricatives are more salient or noticeable to infants and therefore used earlier in lexical representations than phonological detail related to stops; and that toddlers will therefore accept mispronunciations of stops but not of fricatives.

To investigate this hypothesis, we tested Dutch toddlers in a mispronunciation detection task using familiar words. This task allows us to test to what extent word recognition is influenced by single feature mispronunciations. In Experiment 1, we will address the question of whether there are any asymmetries in the recognition of words depending on the change involved at 18 months, an age at which we may expect to find such asymmetries based on the previous studies discussed above. In addition, Experiment 2 is a first exploration of whether we find differences in the perception of manner of articulation with older 25-month-old toddlers, whom we may expect to have more detailed lexical representations (compare the different findings on the use of detail in 18- and 24-month-olds in Mani & Plunkett, 2011a).

## EXPERIMENT 1

Using a language-guided looking procedure (Swingley & Aslin, 2000, 2002) (also commonly referred to as the intermodal preferential looking paradigm (IPL) or looking-while-listening paradigm), we tested recognition of familiar words with initial labial and coronal stops and fricatives and presented subjects with mispronunciations with a change in manner of articulation to see whether we would find asymmetries in children's ability to detect these mispronunciations. Furthermore, we also tested mispronunciations that involved a change in place of articulation. The place mispronunciations were included as a control condition to replicate previous results showing that toddlers are sensitive to changes from labial to coronal but not vice versa (following Van der Feest (2007) and Van der Feest and Fikkert (2013); for other studies showing a preference for labial- over coronal-initial words in young infants and discussion of the labial-coronal asymmetry see, for example, MacNeilage, Davis, Matyear, and Kinney (1999) for production, and Nazzi, Bertoncini, and Bijeljac-Babic (2009) for perception.

We limited ourselves to word-initial mispronunciations in this study, because most models of word recognition, such as Cohort (Marslen-Wilson, 1987) or Shortlist (Norris, 1994), assume that word beginnings are relatively information-rich—at least in trochaic languages such as English or Dutch. Moreover, phonological cues tend to get strengthened in initial position (e.g., Cho, McQueen, & Cox, 2007), and there is evidence that children pay more attention to word-onsets than word-offsets (Jusczyk, Goodman, & Baumann, 1999; Zamuner, 2006; Altvater-Mackensen & Fikkert, 2010; but see Swingley, 2009, and Nazzi & Bertoncini, 2009, for a different view).

### Method

#### *Participants*

Sixty-four monolingual Dutch 18-month-olds (41 boys) participated in the task. Age range was from 17;28 (months; days) to 19;6 (mean age 18;16 or 562 days). An additional 39 children (21 boys) were tested but excluded because of fussiness or unwillingness to participate (14), parents reporting that the children did not know the target words (neither perceptive nor productive) (3), failure to pay attention to the screen on at least half of the trials of each trial type (which may lead to imbalanced exposure and imbalanced contribution to the dataset) (17), parental interference (4), or experimenter error (1). Participants were recruited from the subject pool of the Baby Research Centre in Nijmegen, where all experiments took place. All participants were rewarded with their choice of 10 euros or a small toy, book, or t-shirt.

### *Stimuli*

The visual stimuli consisted of pictures of familiar objects that were displayed against a white background. We used four different pairs of test items in four different conditions: *bal* 'ball' and *boom* 'tree' in the b-condition; *vis* 'fish' and *voet* 'foot' in the v-condition; *deur* 'door' and *duim* 'thumb' in the d-condition; and *zeep* 'soap' and *zon* 'sun' in the z-condition. To estimate the neighborhood size of our test items we inspected the Netherlands-Communicative Development Inventory (N-CDI) of 18- to 24-month-olds (Zink & Lejaegere, 2002). Only two out of the eight test items have one neighbor in the N-CDI cohort (*bal – bad* 'bath' and *voet – hoed* 'hat') making it unlikely that neighborhood size has a large effect on the results of our study. We also calculated the cohort of our test words based on the N-CDI. Chi-square tests showed that cohort sizes were not significantly different from each other for labial vs. coronal and stop vs. fricative words (stop-initial words: 117, fricative-initial words: 91; labial-initial words: 112, coronal-initial-words: 96; $\chi^2(3) = 0.57$, $p = .90$). We obtained parental reports on the children's familiarity with the test words to make sure all children knew at least the test words in the condition they participated in. Filler items were the same across all four conditions and included a duck ('*eend'*), a cow ('*koe'*), a car ('*auto'*), a baby ('*baby'*), a bike ('*fiets'*) and a shoe ('*schoen*'). The fillers were added to keep the children interested in the video and to prevent sequence effects that might be induced by repeated presentation of the test items.

Auditory stimuli were digitally recorded in a sound-proof room by a female native speaker of standard Dutch, using child directed speech, with a sampling rate of 44100 Hz. Test stimuli included target words embedded in the carrier phrase: *Kijk naar de [target]!* 'Look at the [target]!' The target name was either correctly pronounced (CP) or mispronounced (MP). Mispronunciations involved either a change of place of articulation of the initial consonant (MPP) or a change of manner of articulation of the initial consonant (MPM). Correctly and mispronounced test items were matched in intonation contour to prevent that the acoustic realization of our items provided a hint to the status of the word. Paired t-tests showed that the items did not significantly differ in total word duration between CP- and MP-conditions (CP = 542 ms, MPM = 538 ms, MPP = 544 ms; $t_{CP/MPM}(7) = 0.26$, $p = .80$, $t_{CP/MPP}(7) = -0.14$, $p = .89$). Filler stimuli included carrier sentences like *Kun je de koe vinden? Vindt je'm leuk?* 'Can you find the cow? Do you like it?' or *Waar is de fiets? Kun je'm vinden?* 'Where is the bike? Can you find it?'. Next to the carrier sentences, an affirmative second sentence was recorded which was either *Leuk, he?* or *Mooi, he?* 'Nice, isn't it?'

### *Procedure*

Each experiment started with a play session during which the experimenter explained the procedure to the parent. Next, children were seated on their parent's lap facing the data monitor.

TABLE 1
Correct Pronunciations and Mispronunciations of the Test Words Used in Experiment 1

| *Condition* | *CP* | *MPplace* | *MPmanner* |
|---|---|---|---|
| B | [b]al, [b]oom | [d]al, [d]oom | [v]al, [v]oom |
| V | [v]is, [v]oet | [z]is, [z]oet | [b]is, [b]oet |
| D | [d]eur, [d]uim | [b]eur, [b]uim | [z]eur, [z]uim |
| Z | [z]eep, [z]on | [v]eep, [v]on | [d]eep, [d]on |

During the entire experiment, the parents wore headphones over which they heard music intermixed with speech material so that they were unable to hear the timing and content of the auditory stimuli. Parents were instructed to interact as little as possible with their child and to avoid pointing to the screen or naming the objects.

The experiment consisted of 24 trials, of which 14 were test trials and 10 were filler trials. In each trial, the child was presented with the images of the target and distracter object next to each other in silence on a 192 cm diagonal Sony LCD Projection Data Monitor. Each object was about 23 cm wide on the screen and the pairs were horizontally apart by about 20 cm. Each trial lasted for 6.5 seconds. After 2.5 seconds of silence, the carrier phrase with the embedded target word was presented over loudspeakers. Target word offset was followed by another 750 ms of silence. Then the affirmative, second sentence was presented to keep the children alert throughout the trial. After each trial, a flashing light on a black background was shown in silence to redirect the child's gaze to the center of the screen. Six of the 14 test trials included correct pronunciations (CP). Four test trials included mispronunciations in place of articulation (MPP), turning a labial into a coronal in the b- and v- condition, and a coronal into a labial in the d- and z-condition. Four test trials included mispronunciations in manner of articulation (MPM), turning a stop into a fricative in the b- and d-condition and a fricative into a stop in the v- and z-condition. Correct pronunciations and mispronunciations were evenly distributed over all test items so that each test item was presented three times in correct pronunciation, two times with a mispronunciation in manner of articulation and two times with a mispronunciation in place of articulation. The 14 test trials always showed the same pairs of test items. Each test item served as target in one half of the test trials and as distracter in the other half of the test trials. The side at which the target and the distracter appeared was balanced over trials. All test words and the corresponding mispronunciations are summarized in Table 1. The children were randomly assigned to one of the four test conditions (b-, v-, d- or z-initial test words), that is, presented with one of the four test pairs. Sixteen children participated in each condition. Within each condition, subjects were randomly assigned to one of two different orders in which the test trials were presented. The entire experiment was videotaped using a hidden digital camera located beneath the screen. Videos were later compressed to MPEG4 format (25 frames per second).

### *Data analysis*

The looking behavior of the children was coded offline, using the SuperCoder program (Hollich, 2003). A trained coder indicated for each frame of the video (25 frames/second, i.e., one frame per 40 ms) whether the child was looking at the right picture, at the left picture or whether she/he was looking away or shifting the gaze. The coder was blind to target location and trial type. To determine coder reliability a second coder coded 15% of the data. The mean percent of agreement between coders was 96 (mean Cohen's kappa 94.6). A perl script aligned the coding output with information about side of target and precise onset of target word in order to determine the amount of time (in milliseconds) that children spent looking at the target (T) and at the distracter (D) throughout each trial. For each trial, target fixations (TF) were calculated with respect to the total amount of fixations to either the target or the distractor picture ($TF = T/(T+D)$). Difference scores were computed, comparing target fixations in the two seconds *before* target word onset (pre-naming phase) with target fixations in a two second window *after* target word onset (post-naming phase). This ensured that baseline preferences, which may be different for different item pairs and may change over time, were taken into account (see e.g., White & Aslin, 2011; Floccia et al., 2012). A two-second window of analyses was used following Swingley and Aslin (2000) and subsequent studies, as it has been argued that fixations after the first two seconds post-target word onset are unlikely to be influenced directly by the target word. The post-naming phase started 360 ms after target word onset since eye movements before 360 ms after target word onset are not likely to be made in response to the auditory perception of the target word by young children (see, e.g., Swingley & Aslin, 2000; Swingley, 2009). Trials in which the child did not pay attention, i.e., looked at neither target nor distracter (pre- and post-target word onset), were excluded from analysis. Across all subjects and conditions, approximately 5% of trials were excluded for this reason. All subjects completed at least half of the trials of each trial type.

## Results and Discussion

First, effects of mispronunciations of place were investigated in planned comparisons repeated measures 2 x 2 ANOVA with place type (Coronal, Labial) as a between-subjects factor and pronunciation (CP, MPP) as within-subjects factor.

There was a main effect of place type ($F(1,63) = 3.9$, $p = .05$) and pronunciation ($F(1,63) = 6.5$, $p = .01$), but no interaction between place type and pronunciation ($F(1,63) = 0.6$, $p = .44$). Figure 1 illustrates the mean increase in target fixations for coronal- versus labial-initial words on CP-trials and MPP-trials. Given our predictions, we then examined the effects of pronunciation for labial-initial and coronal-initial words individually in a planned comparisons one-way repeated measures ANOVA. For the labial-initial words, there was a significant effect of pronunciation ($F(1,31) = 6.3$, $p = .02$), but not for coronal-initial words ($F(1,31) = 1.4$, $p = .23$). To investigate whether the subjects recognized the target words, planned $t$-tests were conducted comparing difference scores to zero, that is, chance. If a word is recognized, the increase in looking time to the target picture as expressed by the difference scores should be significantly different from chance. This analysis was conducted to ensure that the children recognized the target words when being correctly pronounced and to further investigate if mispronunciations disrupted word recognition. Two-tailed $t$-tests revealed significant increases on CP-trials for coronal-initial targets ($t(31) = 3.4$, $p < .01$) as well as for labial-initial targets ($t(31) = 3.36$, $p < .01$). However, on MPP-trials the increase was significant only for coronal-initial targets ($t(31) = 2.31$, $p = .02$) and not for labial-initial targets ($t(31) = -0.85$, $p = .4$). This indicates that the children recognized the labial and coronal target words when they were correctly pronounced; and that word recognition was hindered when labial targets were mispronounced but not when coronal targets were mispronounced.

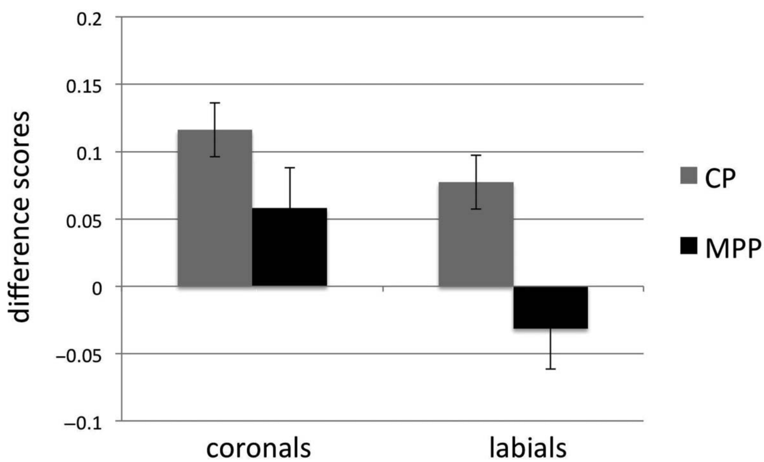


FIGURE 1 Effect of mispronunciations of place of articulation in Experiment 1 (18-month-olds): The graph depicts difference scores (proportion of target fixations after vs before target word onset) and standard errors in the labial (b,v) and coronal (d,z) condition for correct pronunciations (CP) and place mispronunciations (MPP).

Next, we looked at the effects of mispronunciations of manner of articulation. A repeated measures 2 x 2 ANOVA with manner type (Stop, Fricative) as between-subjects factor and pronunciation (CP, MPM) as within-subjects factor showed no significant main effect of manner type ($F(1,31) = 2.3$, $p = .13$), no main effect of pronunciation ($F(1,31) = 0.2$, $p = .8$) and no interaction ($F(1,31) = 0.9$, $p = .34$), suggesting there were no differences in word-recognition of stop-initial or fricative-initial target words, and no significant overall effects of mispronunciations of manner on word recognition. Figure 2 illustrates the mean increase in target fixations for stop- versus fricative-initial words on CP-trials and MPM-trials. Again, given the predictions of the study, we compared effects of manner mispronunciations on stop-initial versus fricative-initial words individually in a planned comparisons one-way repeated measures ANOVA. This revealed a significant effect of pronunciation on fricative-initial targets ($F(1,31) = 4.6$, $p = .03$), but not on stop-initial targets ($F(1,31) = 0.15$, $p = .69$), indicating that the 18-month-olds did detect manner mispronunciations on fricative-initial words. To examine whether the target words were recognized, planned two-tailed *t*-tests comparing difference scores to zero were conducted. There was a significant increase in target looking on CP-trials for both fricative-initial targets ($t(31) = 4.2$, $p < .01$) and stop-initial targets ($t(31) = 2.6$, $p = .01$), indicating that the children recognized the target words when they were correctly pronounced. On MPM-trials the increase was neither significant for fricative-initial targets ($t(31) = .42$, $p = .94$), nor for stop-initial targets ($t(31) = 0.4$, $p = .69$). This suggests that word recognition was impaired to some extent when stop-initial words were pronounced with a mispronunciation of manner of articulation, even though there was no significant effect of pronunciation when comparing CP- versus MPM- trials for the stop-initial words (indicating that the mispronunciation effect is rather weak).

The results from Experiment 1 show that Dutch 18-month-olds were able to detect place of articulation mispronunciations involving a change from labial to coronal, but not vice versa. This

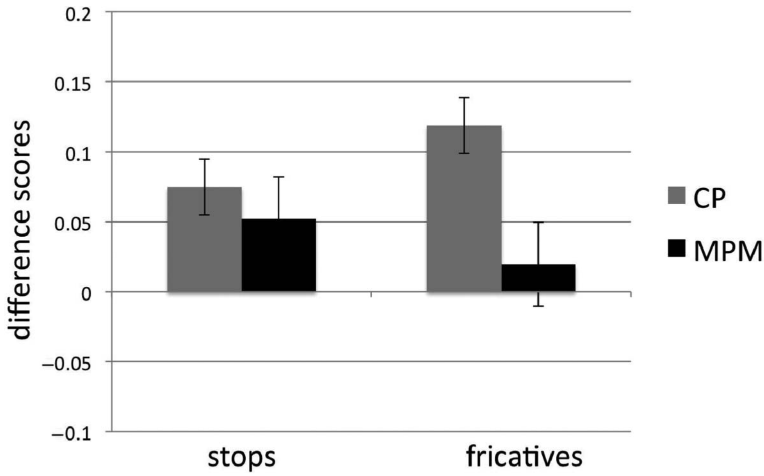


FIGURE 2 Effect of mispronunciations of manner of articulation in Experiment 1 (18-month-olds): The graph depicts difference scores (proportion of target fixations after vs before target word onset) and standard errors in the stop (b,d) and fricative (v,z) condition for correct pronunciations (CP) and manner mispronunciations (MPM).

confirms our predictions and previous findings of asymmetries in sensitivity to switches that involve place of articulation contrasts (Fikkert, 2010; Fennell et al., 2010, 2013), as well as asymmetries reported in an earlier mispronunciation detection task involving place of articulation features (Van der Feest, 2007; Van der Feest & Fikkert, 2013). We extended these findings by investigating the perception of manner of articulation as well: Dutch 18-month-olds showed less robust sensitivity to manner of articulation mispronunciations. While they showed sensitivity to manner mispronunciations that involve a change from fricative to stop, sensitivity to mispronunciations that involve a change from stop to fricative was very limited. Although the effects we found were not very strong, the direction of the effects was in line with our prediction and corresponded with previous findings of asymmetries in sensitivity to changes of manner of articulation in a word-learning task (Altvater-Mackensen & Fikkert, 2010) and asymmetries reported in a mispronunciation detection task (Mani & Plunkett, 2008b). Note that perceptual asymmetries are found with different age groups, different tasks and at different contrasts providing strong evidence that perceptual asymmetries are not an artifact of task demands.

As a first follow-up to the results of Experiment 1, we conducted a second experiment to explore whether the patterns found in Experiment 1 persist in older toddlers. Our goal was to test sensitivity to mispronunciations of manner of articulation with an older age group in a second experiment, because the 18-month-olds only showed evidence for limited sensitivity to mispronunciation involving manner of articulation, and we wanted to explore whether and how sensitivity to these mispronunciations develops. We focused on the question whether older children show more robust detection of manner mispronunciations and if so, whether we can find any evidence for perceptual asymmetries of manner of articulation in older toddlers. We focused on sensitivity to mispronunciations of manner of articulation features, considering that several previous studies explored (the development of) asymmetries in place of articulation features in older children and adults. This labial-coronal distinction has been quite extensively discussed elsewhere (MacNeilage et al., 1999; Fikkert & Levelt, 2008; Nazzi, Bertoncini, & Bijeljac-Babic; 2009, among others) and we refer to Van der Feest (2007) and Van der Feest and Fikkert (2013) for results on asymmetric perception of labial and coronal mispronunciations in Dutch 24-month-olds.

## EXPERIMENT 2

In Experiment 2, we tested 25-month-olds using the same labial-initial stimuli as in the b- and v-condition of the first experiment, focusing on the effect of mispronunciations of manner, adding mispronunciations of place as a control: the results from Experiment 1 as well as previous studies on perception of place (as discussed above) show that younger children can detect changes from labial to coronal, so we predicted that the older toddlers in Experiment 2 would be able to do so as well. We further choose to test the toddlers on the labial stimulus set rather than on the coronal stimulus set because earlier studies have shown that children prefer labial-initial over coronal-initial words in perception (Nazzi, Bertoncini, & Bijeljac-Babic, 2009), and we wanted to maximize children's attention to the task. If older toddlers have learned to represent manner of articulation in more detail in their lexicon (as they gain more experience with their language in perception and production and add more words to their lexicon), we may see that 25-month-olds robustly detect mispronunciations of manner of articulation on both stop- and fricative-initial labial words.

### Method

#### *Participants*

Thirty-two monolingual Dutch 25-month-olds (19 boys) were tested using the same task as in Experiment 1. Age range was from 24;01 (months; days) to 25;16 (mean age 25;6 or 768 days). An additional twelve children were tested but excluded because of fussiness (11) and previously unreported Dutch-Letvian bilingual language input at home (1).

#### *Stimuli*

Stimuli were identical to the stimuli used in the b- and v-condition of Experiment 1.

#### *Procedure*

The procedure was identical to Experiment 1. Sixteen children were tested in the b-condition, i.e., presented with the test items *boom* ('tree') and *bal* ('ball'), and 16 children were tested in the v-condition, that is, presented with the test items *voet* ('foot') and *vis* ('fish').

### *Data analysis*

Data analysis was identical to Experiment 1.

## Results and Discussion

A repeated measures 2 x 2 ANOVA was conducted to investigate the effect of mispronunciations of manner, with word type (stop-initial, fricative-initial) as a between-subjects factor and pronunciation (CP, MPM) as within-subjects factor. Results showed a significant effect of pronunciation ($F(1,31) = 5.12$, $p = .03$), but no main effect of word type ($F(1,31) = 1.07$, $p = .3$) and no interaction between word type and pronunciation ($F(1,31) = 0.01$, $p = .9$). To examine whether the target words were recognized, planned two-tailed *t*-tests comparing difference scores to zero were conducted. Target looking significantly increased on CP-trials for both the fricative-initial ($t(15) = 4.3$, $p < .01$) and the stop-initial words ($t(15) = 2.3$, $p = .04$), but not on either of the mispronounced trials (fricative-initial words: $t(15) = 1.37$, $p = .19$; stop-initial words: $t(15) = -0.21$, $p = .83$). These results indicate that the word recognition of 25-month-olds was hindered by mispronunciations involving a change in manner of articulation on both labial stops and labial fricatives.

A 2 x 2 ANOVA investigating the effect of mispronunciations of place (the control condition in this experiment), with word type (stop-initial, fricative-initial) as a between-subjects factor and pronunciation (CP, MPP) as within-subjects factor showed a main effect of pronunciation ($F(1,31) = 8.7$, $p < .01$), no effect of word type (stop-initial, fricative-initial) (note that all words were labial-initial, so no effect of word type was predicted here) ($F(1,31) = 0.09$, $p = .75$) and no interaction between pronunciation and word type ($F(1,31) = 0.06$, $p = .79$). Difference scores were significantly different from zero on CP-trials but not on MPP-trials, for both the fricative-initial condition (CP: $t(15) = 4.3$, $p < .01$, MPP: $t(15) = -0.4$, $p = .7$) and the stop-initial condition (CP: $t(15) = 2.3$, $p = .04$, MPP: $t(15) = -0.3$, $p = .76$). These results show that the 25-month-olds' word recognition was, as expected, hindered by mispronunciations involving a change from labial to coronal, for both stops and fricatives. Figure 3 illustrates the mean increase in target fixations for b- and v-initial words in correctly pronounced and mispronounced trials (CP, MPM and MPP).

# GENERAL DISCUSSION

The current study demonstrates that toddlers' sensitivity to place and manner mispronunciations is initially asymmetric. While 18-month-olds are sensitive to changes from labial to coronal and from fricative to stop, they do not detect changes in the opposite direction. In contrast, 25-month-olds robustly detect changes from stop to fricative. These findings illustrate that toddlers are not equally sensitive to all types of mispronunciations, but that the *direction* of change is crucial. It further suggests that sensitivity to mispronunciations emerges in the course of development.

The results from Experiment 1 show evidence for perceptual asymmetries of the labial-coronal contrast in familiar words at 18 months. They replicate earlier findings with stops, as discussed in the introduction and results sections, and extend them to fricatives. Furthermore, the perceptual asymmetry attested for the stop-fricative contrast complies with findings from Mani and Plunkett

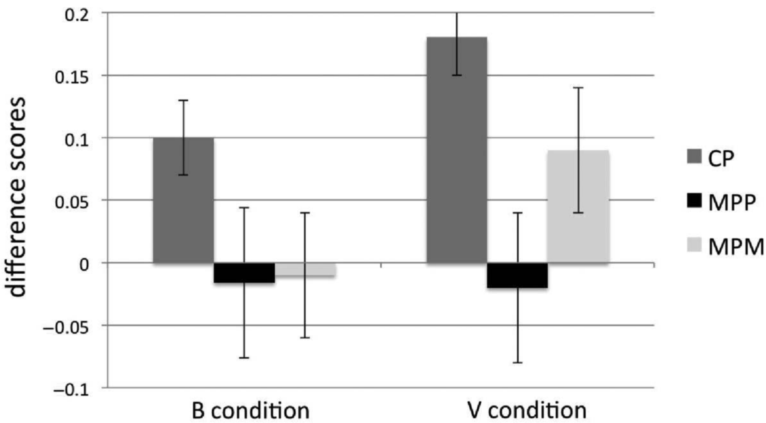


FIGURE 3 Effect of mispronunciations of place and manner of articulation in Experiment 2 (25-month-olds): The graph depicts difference scores (proportion of target fixations after vs before target word onset) and standard errors in the b- and v- condition for correct pronunciations (CP), place mispronunciations (MPP) and manner mispronunciations (MPM).

(2008b), which show that English 18-month-olds are more likely to spot mispronunciations of fricative-initial words than to spot mispronunciations of stop-initial words. Experiment 2 reveals that this effect changes with age: while 18-month-olds only showed a tendency towards detecting manner mispronunciations on labial stops, 25-month-olds robustly detected changes from stop to fricative (as well as from fricative to stop) on labial targets.

For a more extensive discussion on the labial-coronal asymmetry, which has been documented in multiple previous studies, we refer to Van der Feest (2007) and Van der Feest and Fikkert (2013), as well as MacNeilage et al. (1999) and Fikkert and Levelt (2008) for production and Nazzi, Bertoncini, and Bijeljac-Babic (2009) for perception. We will here focus on a discussion of manner of articulation effects, explore different explanations for our findings and argue for a lexical approach that accounts for asymmetries in the detection of both place and manner changes by assuming the same underlying mechanisms.

## Bottom-up Mechanisms

### *Asymmetries in phoneme categorization*

To detect a mispronunciation, a child first has to correctly categorize the perceived acoustic signal into her language's phonemes. In the introduction, we reviewed a number of studies showing asymmetries in the perception of phoneme contrasts. For instance, infants may detect a change from /y/ to /u/, but not a change from /u/ to /y/ (Polka & Bohn, 1996). These asymmetries have mainly been documented for vowels and have been attributed to the focality, peripherality, or prototypicality of the vowel (Schwartz et al., 2005; Polka & Bohn, 2011; Kuhl et al., 1992). However, it is unclear how these concepts can be applied to the discrimination of stops and fricatives. Which consonant should be considered more peripheral or prototypical?

Both mispronunciations and correct pronunciations included regular stop and fricative exemplars. Thus, we did not use any atypical or nonnative consonants, making it unlikely that one of the consonant was perceived as a less good example of its class. One might, however, argue that if a change from a less to a more prototypical vowel is easier to detect, a change from a less to a more prototypical consonant might also be easier to detect. Given that stops are most distinct to vowels (Jakobson, 1941) and that stops are the first consonants to be acquired in babbling (Gildersleeve-Neumann, Davis, & MacNeilage, 2000), we might argue that stops are more prototypical consonants than fricatives (in a general sense). This would imply that a change from fricative (nonprototypical) to stop (prototypical) should be easier to detect than vice versa. Indeed, our results are in line with this prediction. Yet, Dutch 14-months-olds do not show any asymmetry in their discrimination of stops and fricatives in a pure discrimination task (Altvater-Mackensen & Fikkert, 2010). Since a discrimination task does not reveal any directional asymmetries in phoneme discrimination, we argue that it is unlikely that a basic asymmetry in acoustic phoneme perception causes our asymmetric results.

Two other factors that have been discussed to influence phoneme perception in infancy and that might potentially cause asymmetries are acoustic characteristics and frequency factors (Anderson et al., 2003; Narayan et al., 2010; Pons et al., 2012). We will first elaborate on the influence of acoustic factors that might cause perceptual confusion of sounds or differences in cue weighting. We will then come back to the potential influence of frequency when discussing item characteristics as a source for the observed perceptual asymmetries in the current experiments.

### *Perceptual confusion*

One explanation for asymmetries in word recognition arises from perceptual confusion. Depending on the direction of mispronunciation, different phonetic cues must be used to detect changes. Some cues might be easier to integrate than others. For example, in the case of voicing in Dutch, perceiving prevoicing is a very reliable acoustic cue that a stop is voiced. On the other hand, acoustic cues for voicelessness are much less stable (Van Alphen & Smits, 2004). This may explain why young Dutch-learning children only detected mispronunciations involving inappropriate voicing of voiceless segments (see Van der Feest, 2007; Van der Feest & Fikkert, 2013, for arguments for a lexical approach to these asymmetries in the perception of voicing). This acoustical argument is further strengthened by the fact that adults also show asymmetries in perception. Some phonemes are more likely to be confused than others: for example, /k/ might be mistaken as /p/ or /t/ under noisy circumstances, but /p/ or /t/ are hardly ever misperceived as /k/ (Benki, 2003, for English; Smits, Warner, McQueen, & Cutler, 2003, for Dutch). Asymmetric confusion of certain sounds can therefore be expected from an acoustical point of view (see Ohala, 2005; Fennell et al., 2010, 2013) regarding the possible effects of acoustic variability and confusability of different places of articulation on early perception of stops.

But manner of articulation contrasts are robust in perception and seldom confused by adults and older children (Cole, 1981; Benki, 2003; Smits et al., 2003). In an identification-in-noise task, adults seldom confuse manner of articulation features in either direction in nonsense CV-syllables (Benki, 2003). Similar results have been reported for the detection of mispronunciations in fluent speech, that is, during word recognition (Cole et al., 1978; Cole, 1981). We therefore deem it unlikely that the toddlers in our study perceptually confused fricatives with stops.

Because manner of articulation features are robust in perception, we would have expected strong mispronunciation effects rather than the weaker effects that we observed in 18-month-olds.

However, certain asymmetries in the detection of manner contrasts have been reported: English adults detect mispronunciations that involve a change from stop to fricative, for example, the change from *bird* to ‘vird’, more often than changes from fricative to stop (Cole et al., 1978). Cole and colleagues propose that especially for voiced fricatives, the frication noise in fluent speech might sometimes be too short and of too low intensity to be perceived accurately, resulting in the perception of a stop. Yet the direction of the asymmetry in adults’ perception of stops and fricatives is in the *opposite* direction of the one observed in the current study. Also, Cole (1981) reports that children and adults detect mispronunciations that involve stops and fricatives better than any other kinds of mispronunciations; and he does not report any asymmetry between stops and fricatives depending on the direction of change. Remember also that Altvater-Mackensen and Fikkert (2010) show that Dutch 14-month-olds are perfectly able to detect a change from word-initial /p/ to /f/ in a pure discrimination task. Given the lack of asymmetries in the perception of stops and fricatives in these studies, it is unlikely that perceptibility of acoustic cues is the crucial factor that leads to the asymmetries observed in our study.

### *Cue weighting*

Another possible source of the observed asymmetries is that younger children weigh certain acoustic cues differently from older children and adults. In a series of experiments on the perception of fricatives, Nittrouer and colleagues show that children weigh transitional and noise cues differently from adults (Nittrouer, 2002; Nittrouer, Lowenstein, & Packer, 2009). Young children rely much more on formant transitions than on amplitude information to categorize fricative stimuli, while adults use both transitional cues and noise information (Nittrouer, 2002). However, the described difference in cue weighing does not provide a sufficient explanation for the asymmetries between stops and fricatives found in our study. For the manner mispronunciation trials we did not alter place of articulation. Hence, information on formant transitions, indicating place of articulation, is not of much help in detecting the difference between stops and fricatives in *voet* ‘foot’ and its mispronunciation *boet,* or *boom* ‘tree’ and its mispronunciation *voom*.

On the basis of the current study we cannot exclude the possibility that children weigh information on frication noise in fricatives differently from cues on closure and burst in stops. Differences in cue-weighing might be related to the reliability of acoustic information. In casual speech stops sometimes turn into fricatives because of lenition phenomena, but fricatives seldom turn into stops (e.g., Ohala, 2005). Hence, perceiving a stop could be more informative than perceiving a fricative. Frication in the signal might either be a ‘true’ fricative or a spirantized stop. In contrast, a stop in the signal is most likely to be a stop (and not a fricative). If children are sensitive to the reliability of acoustic cues, they might rely more on stop cues compared to fricative cues resulting in asymmetric perception of mispronunciations. Because stops turn into fricatives more often than vice versa, they might also be more willing to accept a fricative for a stop than to accept a stop for a fricative. There are, however, a number of counter-arguments against this assumption.

First of all, lenition, that is, the weakening of a stop that results in the production of a fricative, is cross-linguistically most likely to occur in prosodically weak positions. The mispronunciations in our stimuli, however, occurred word-initially in the accented position in the sentence. This is not a position in which lenition is likely to occur. Moreover, lenition is not a typical phenomenon in Dutch. If children are sensitive to variation due to lenition, children would have to generalize from more variability in prosodically weak positions and assume similar variability (which they do not encounter in the input) in word-initial positions. The fact that infants are well able to discover statistical probabilities in specific positions (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993) makes it unlikely that toddlers are unable to track the reliability of an acoustic cue for a specific position within the word. One might argue that there is no need to compute the reliability of an acoustic cue per position, but adult data show that adjustments to speech alternations can be selective (Jesse & McQueen, 2007). Knowledge on how a speaker produces a certain sound in onset position influences an adult's perception of this sound in onset but not in coda position.

A second argument against a greater reliance by children on acoustic cues for stops than for fricatives is that adults typically modify their speech when speaking to infants or children. Infant Directed Speech (IDS) is characterized by higher pitch range, slower speaking rate and more careful articulation than Adult Directed Speech (ADS) (e.g., Kuhl et al., 1997). Hence, sound contrasts are presumably enhanced rather than weakened in infant directed speech. Consequently, lenition should occur less frequently in IDS. Children would have to base their reliability weighing on surrounding ADS and not on speech that is addressed to them in order to be influenced by lenition when acquiring perceptual category boundaries.

Third, children show an opposite substitution pattern than adults in their own speech: they frequently replace fricatives with stops in early words, particularly in word-initial position, but they hardly ever replace stops with fricatives (Fikkert, 1994; Gildersleeve-Neumann et al., 2000). Since the production of fricatives demands higher articulatory control than the production of stops, this pattern may reflect children's articulatory difficulties with producing fricatives accurately (Gildersleeve-Neumann et al.). This could also be reflected in children's representations, as it is often assumed that children also consider their own output as input when learning sound categories suggesting a tight link between production and perception (Ferguson & Farewell, 1975; MacNeilage & Davis, 2005). To arrive at a cue weighing that takes stop cues as more reliable than fricative cues, the child would thus have to ignore the information from her own output.

Taken together, it is questionable that the ability to differently weigh acoustic cues in word recognition is a probable source of children's failure to detect certain mispronunciations. We do not argue against a large role of acoustic cues in the early lexicon, but based on the arguments above, there is no reason to assume that Dutch-learning children would not be able to use the cues for both stops and fricatives, especially in prosodically strong positions in which the realization of stops and fricatives are most pronounced.

## Top-down Mechanisms

### *Task demands*

A common explanation for children's failure to use all phonological detail in word learning and word recognition is high task demand, leading to cognitive processing overload. Learning a word involves transferring the variable acoustic input to a stable, more abstract phonological representation and associating it with a meaning. It has often been argued that task demands are simply too high in a task where infants need to map two unknown objects to two unfamiliar, similar sounding words and that they fail to use phonological detail that they are very well able to use in less demanding tasks (Stager & Werker, 1997; Werker & Curtin, 2005; Yoshida et al., 2009). Although word learning—and to a lesser extent word recognition—certainly is a challenging task, it is not obvious how task demands would lead to asymmetries in mispronunciation detection in our study. Models like PRIMIR (Werker & Curtin, 2005) assume different layers in lexical representations containing different kinds of information. Depending on age, familiarity with the word, demands of the task, etc., children will use different types of the stored information to perceive speech and recognize words (see also Werker, Fennell, Corcoran, & Stager, 2002). We are not claiming that these factors do not influence children's performance in word recognition tasks. Yet task demands as well as other item-specific factors were kept as constant as possible for stop- and fricative-initial words in our study. Although differences in age, task demands or general language and word experience might explain the difference in performance between 18- and 25-month-olds, it is unlikely that the asymmetry between stops and fricatives within the 18-month-olds was primarily caused by any of these factors, as we will argue in the following paragraph.

### *Item characteristics*

The 18-month-olds performed overall worst on detecting mispronunciations in the d-condition: they did not detect mispronunciations of either place or manner of articulation in /d/-initial words (while they detect place mispronunciations on /b/-initial words, manner mispronunciations on /z/-initial words and both manner and place mispronunciations on /v/-initial words). One could possibly argue that this means that they had a harder time recognizing test items starting with /d/. However, all target words were frequent words that 18-month-old children were likely to know. Body parts in particular are reported to be acquired early (Tincoff & Jusczyk, 2011; Bergelson & Swingley, 2012) and one of our /d/-initial items was the word *duim* 'thumb'. In addition, children's familiarity to all test words was confirmed through parental report for all participants and the children showed recognition of all test items in correctly pronounced trials. This makes it unlikely that the children did not know the target words well enough to be in principle able to systematically detect stop and coronal mispronunciations.

Another item-specific factor that might have influenced the results is the number of words that sound similar to the target words and their corresponding mispronunciations. Mani and Plunkett (2011b) report an effect of cohort size on English 24-month-olds' word recognition: while recognition of words from large cohorts is hindered, words from small cohorts are recognized faster. Based on these results, we might expect that the number of words that overlap with the target and its mispronunciations influences children's looking behavior. However, our target words did not significantly differ in cohort or neighborhood size (see stimulus description for more detail). The same necessarily holds for the corresponding mispronunciations since we controlled for directional effects by changing, e.g., a stop-initial word into a fricative-initial word and vice versa. Cohort size effects are thus neither a probable source of the observed asymmetries. Note that Mani and Plunkett (2011b) also only report cohort size effects for 24-month-old children, but not for 18-month-olds, suggesting that cohort size only influences word recognition in older children.

Next to its cohort size, the frequency of the initial consonant might also be of importance (remember from the introduction section that work on asymmetries in infants' phoneme discrimination is thought to be influenced by phoneme frequency; Anderson et al., 2003; Narayan et al., 2010; Pons et al., 2012). Because it is difficult to estimate the actual frequency with which a child heard a certain sound in word-initial position, we calculated the frequencies of the different word-initial consonants using CELEX (Baayen, Piepenbrock, & Van Rijn, 1993) and ranked all consonants based on their token frequencies using a Guttmann-scale (for a similar procedure see Levelt, Schiller, & Levelt, 1999; Torgerson, 1963). All word-initial consonants used in our study belong to the most frequent word-initial consonants in Dutch (token frequencies for all four consonants are above 1.5 million). Importantly, there is no systematic difference between labials and coronals or between stops and fricatives (ranked order from most to least frequent: d, v, z, b). If frequency would have influenced our result, we would have expected that d-initial targets should have had an advantage given that /d/ is the most frequent sound in word-initial position from our stimulus set, yet children seem to perform worst on d-initial words. This questions an explanation for the asymmetries observed in 18-month-olds based on the frequency of the involved sound.

### *Lexical representations*

All of the above-mentioned factors, as well as acoustic cue-weighing, may ultimately contribute to the gradual build up of lexical representations. Several researchers have put forward the idea that the amount of detail available in lexical representations varies over the course of development. Detail might for example be added through repeated exposure to a word (e.g., Plunkett, Sinha, Moller, & Strandsbury, 1992; Gerken, Murphy, & Aslin, 1995) or through the need for contrasting a newly learned word with other words already stored in the lexicon (e.g., Metsala, 1999; Walley, 2005). Following a similar line of reasoning, Fikkert (2010) proposes that children's initial representations do not contain all relevant phonological features and that children gradually add detail to their representations of words. Importantly, her model assumes that the addition of detail follows a path that is related to the phonological *markedness* of features: children start out with specifying 'marked' features only. In that way, markedness can be considered a measure for the contrastive saliency of a phonological feature. Which values are marked or unmarked depends on how the features pattern in the phonology of a particular language. Since only stored information can mismatch with information extracted from the acoustic signal, the detection of a mispronunciation thus depends on whether a feature is specified in the child's mental lexicon or not (see Lahiri & Reetz (2002, 2010) and Lahiri (2011, 2012) for a similar approach to adult word recognition).

The crucial question for such an account with respect to our data is what member of the stop-fricative contrast would be considered "marked" and therefore specified. In the phonological acquisition literature, fricatives are assumed to be featurally more marked than stops (as already argued for by Jakobson, 1941). Given the widely cited idea that children start out producing unmarked structures, the finding that children frequently replace fricatives by stops in babbling and in early words, while the reverse pattern is rarely observed (Fikkert, 1994; Gildersleeve-Neumann et al., 2000), also suggests that fricatives are marked while stops are unmarked in terms of manner of articulation. This argument strongly relies on the order of appearance of stops and fricatives in children's productions. This order, one could argue, could be influenced exclusively by children's articulatory abilities rather than by a more general system of markedness. However, another way to conceptualize markedness is to describe phonological contrast by the presence or absence of a specific feature (see Trubetzkoy (1939) and subsequent studies for the ideas of the Prague school of structuralism). In our case, fricatives would be marked by the presence of the feature [continuant], while stops would lack this feature. This account is linked to the assumption that only marked features will spread to other segments in the course of phonological processes, i.e., stops can take on the feature [continuant] in certain circumstances, but fricatives will usually not become stops in adult speech (Clements, 1985, 2006; McCarthy, 1988). Taken together, fricatives can be considered to be more marked than stops. We might thus assume that fricatives would probably be lexically specified, while stops would remain unspecified for manner of articulation features.

The asymmetry in the detection of stop and fricative mispronunciations logically follows from these assumptions: The first consonant in fricative-initial words like *voet* 'foot' would be specified. When the child hears a stop-initial mispronunciation like *boet*, the acoustic characteristics of a stop are perceived in the signal. Because this acoustic information mismatches the stored (fricative) manner of articulation feature, the child will detect the mispronunciation. In contrast, the first consonant in a stop-initial word like *boom* 'tree' would be unspecified for its manner of articulation. When the child perceives a fricative-initial mispronunciation like *voom*, she will extract the marked acoustic characteristics of a fricative from the signal. This will not lead to a mismatch with the stored representation since the initial consonant is not specified for (stop) manner of articulation and consequently, the mispronunciation will not be reliably detected; *voom* is a good enough candidate for *boom*.

Note that the mechanism relies on the match between the information extracted from the acoustic signal and the information stored in the lexical representation. Following the proposal of Lahiri and Reetz (2002, 2010), a feature extracted from the signal that mismatches a stored feature will cancel out activation of the corresponding word. A feature extracted from the signal that matches—or at least does not mismatch—a stored feature will keep the corresponding word activated. This implies a certain direction of the effect that is grounded in the mechanisms of lexical access: matching features add to activation of a certain word, mismatching features will reduce activation of this word, and features that are neither matching nor mismatching (i.e., features that are not lexically marked) will not alter its activation. Table 2 summarizes such a matching procedure and the resulting predictions for fricative- and stop-initial words.

TABLE 2
Matching Procedure and Predictions

| *Familiar word* | *Fricative-initial[v]oet* | *Stop-initial[b]oom* |
|---|---|---|
| Stored representation | fricative | Ø |
| | ⇓ | ⇓ |
| Mispronounced form | [b]oet | [v]oom |
| Extracted cue | stop | fricative |
| | ⇓ | ⇓ |
| Matching | Mismatch | No mismatch |
| Mispronunciation detected | Yes ✓ | No × |

A similar logic applies to the asymmetries observed in the detection of mispronunciations involving place contrasts (in the current Experiment 1 and in previous studies): labial stops and fricatives are considered to be marked for place of articulation while coronal stops and fricatives are unmarked for place in Dutch (and possibly cross-linguistically). Consequently, mispronunciations on labial targets, like *doom* for *boom* 'tree' or *zoet* for *voet* 'foot', are detected. But mispronunciations on coronal targets, like *beur* for *deur* 'door' or *von* for *zon* 'sun', are not detected (see Fikkert, 2010, and Van der Feest & Fikkert, 2013, for a more extensive discussion on place of articulation in early representations in Dutch). Interestingly, children's overall performance was worst in the d-condition where neither place nor manner mispronunciations were detected by the 18-month-olds. Considering that under a phonological account, /d/ would be the least marked segment of the four segments that we tested, it seems reasonable that children perform better on the labial stop /b/ when they start to acquire and represent manner of articulation. Unlike coronals, labials are already marked for place of articulation and this may facilitate children's overall attention to the exact acoustic realization of labial segments as compared to coronal segments. Put differently, toddlers' representation of /d/ may be broader in the beginning, and their representation of /b/ may be more restricted. This is because /d/ would be unspecified for PoA and MoA under the lexical approach.

This would also fit Fennell et al.'s (2010, 2013) suggestion that acoustic variability drives perceptual asymmetries. Indeed, /d/ is acoustically more variable than /b/ as, e.g., it frequently undergoes assimilation (Paradis & Prunet, 1991, and papers therein). Children might thus use acoustic stability as a cue to lexically represent the corresponding phonological feature. Note that we do not want to imply here that representation of a specific feature is gradient. Yet, if specification is a step-wise process, it is entirely possible that some features might be represented before others, for example, [labial] might be represented before [voiced] (see also Van der Feest, 2007). Different phoneme characteristics, such as frequency (Anderson et al., 2003; Narayan et al., 2010; Pons et al., 2012), acoustic discriminability (Polka & Bohn, 2003, 2011; Schwartz et al., 2005) and acoustic stability (Fennell et al., 2011, 2013), might thereby help the child to determine which features should be lexically marked. Although this does not represent the traditional view on linguistic markedness, under such an account an acoustic-phonetic approach is not necessarily incompatible with a lexical featural approach. Rather, the structure of the phonological system as well as acoustic characteristics and cues associated with a certain sound contrast might provide the basis for children's acquisition of the featural system of their native language.

Importantly, the outlined lexical account does not only predict the different asymmetries observed in word recognition, and the results from Experiment 1 in particular, but also those observed in word learning by assuming similar mechanisms. In word recognition, children only detect mispronunciations that involve the change of a specified feature, hence mispronunciations that replace a target fricative by a stop or a target labial by a coronal. Similarly, infants are able to detect changes in newly learned words that involve marked features, but not those that involve unmarked features because only marked features are stored (see Altvater-Mackensen & Fikkert, 2010) for a detailed discussion on asymmetries in word learning). In our view, one of the merits of a lexical approach is that it potentially provides a unifying account for asymmetries of different contrasts and at different stages of lexical development. Furthermore, it might be suitable to capture asymmetries in both the perception and production of early words: in perception infants will only detect those mispronunciations that change specified features, for example, a change from fricative to stop, but not vice versa; in production errors will involve the loss rather than the addition of a feature, for example, fricatives turn into stops, but not vice versa (for a discussion of the lexical approach for production errors and the relation between perception and production we refer to Altvater-Mackensen & Fikkert, 2010, 2013). The outlined account is in principle not restricted to labial-coronal or stop-fricative asymmetries. It could be expanded to any other given sound contrast, as long as it can be captured in terms of a specific feature difference. This also means that the observed asymmetries should not be restricted to Dutch. Indeed, German and English toddlers seem to show a similar asymmetry for the perception of the stop-fricative contrast (Mani & Plunkett, 2008b; Altvater-Mackensen, 2010). Nevertheless, the phonological system of contrast might differ across languages depending on the specific realization of phonological features in different languages, giving raise to different systems of markedness (Dresher, 2009). This would imply that depending on the language to be learned, developmental paths and perceptual asymmetries might differ (see Altvater-Mackensen, 2010, for a detailed discussion).

A lexical approach would also have to account for our finding from Experiment 2 that older children are able to detect mispronunciations of stop-targets. There are different ways to couch this developmental change. One way is to assume that children add more and more detail to their lexical representations over the course of development. If eventually the unmarked member of a contrast gets specified, an asymmetrical detection of mispronunciations is no longer expected. If stops get specified for manner of articulation, a perceived fricative mismatches a stored stop and the mispronunciation will be detected. Alternatively, certain features could remain unspecified even in the adult lexicon (Lahiri & Marslen-Wilson, 1991; Friedrich, Lahiri, & Eulitz, 2008), but the cue-matching system becomes more sensitive to subtle differences among matches, no-mismatches, and mismatches. Stops may remain unspecified (e.g., for manner of articulation), but the mature system will require a match between signal and lexical representation, if a fricative cue is extracted from the signal. A no-mismatch between unspecified stop in the representation and fricative-cue in the signal would then no longer be good enough to lead to unimpaired word recognition and the mispronunciation would also be detected in stop-targets. It would, however, be unclear what might trigger this latter change in the matching system. The use of more and more detail in the child's lexical representation on the other hand would be compatible with a continuous view on lexical development.

## Conclusion

The current study investigated toddlers' ability to detect single-feature mispronunciations in familiar words by systematically changing the place and manner of articulation of word-initial consonants. The results indicate that 18- and 25-month-olds do not detect all mispronunciations equally well. We considered different explanations for our results. Neither acoustic approaches nor general cognitive approaches seem to be able to provide sufficient explanations for the observed asymmetric patterns. Acoustic characteristics and cognitive factors such as task demands certainly affect toddlers' performance in word recognition tasks. Nevertheless, we argue that these are not likely to cause the observed perceptual asymmetries. Instead we argue for a lexical approach to account for the data that stresses the nature of children's early lexical representations as source of the asymmetry in 18-month-olds' ability to detect mispronunciations, as well as the differences observed between 18- and 25-month-olds. Lexical representations that initially lack certain phonological features can account for the finding that not all changes are detected equally well and that sensitivity emerges in the course of development. A lexical account allows for a unified approach that captures asymmetries in sensitivity to different phonological features. Assuming the same underlying mechanisms for difficulties in word learning and word recognition, it can provide a continuous view on lexical development in infants and toddlers.

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