Chapter 2
Phonological Features Mediate Object-Label Retrieval and Word Recognition in the Visual World Paradigm

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2.1 Introduction: The Role of Phonological Information During Word Recognition in Toddlers

Young word learners have a considerable challenge facing them. With just a few exposures to a word, they must learn the sounds associated with this word and be able to retrieve this information when they hear a new token of this word, or see an object associated with this word. Research has long focused on the amount of detail young children store with regard to the sounds of words and a majority of studies find that children have detailed phonological representations of words (Swingley and Aslin 2000, 2002; Mani and Plunkett 2007, 2010a; White and Morgan 2008). However, it remains a matter of some discussion whether children access this phonological detail during word recognition, with a number of researchers suggesting that access to phonological detail may be restricted by the task employed by a given study, or the kinds of words being tested, or the age-group of the children (see Mani 2011, for a review of studies).

The visual world paradigm provides a particularly promising tool to investigate these questions (Tanenhaus et al. 1995). Experiments employing this paradigm typically present participants with an array of visual images on a screen followed by an auditory label, which is in most cases related to one or more of the images on the screen. Participants' eye-movements across the array of images are monitored before and after they hear the auditory stimulus and any changes in gaze-fixations subsequent to the presentation of the auditory stimulus are typically interpreted as

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a response to this stimulus. The paradigm has been successfully used in numerous studies to investigate mechanisms of language processing, and more specifically to tap into the phonological processes associated with word recognition in adults (see Huettig et al. 2011, for a review). For instance, Allopenna et al. (1998) presented listeners with images of a target, an onset competitor that shared the initial consonant with the target label and a rhyme competitor that rhymed with the target label. Results show that adults fixated both the target and the onset competitor upon hearing the beginning of the target label. Looks to the onset competitor decreased when the acoustic signal mismatched the phonological make-up of the onset competitor while looks to the target increased with increasing matching phonological information. Fixations of the rhyme competitor, however, only started to emerge following the offset of the target label. These findings suggest that lexical access is modulated by phonological similarity, that onset-overlapping words compete with the target label during word recognition and that rhyme overlap further constrains lexical selection. Magnuson et al. (2007) extended these findings by showing that not only phonological overlap but also word frequency and the phonological structure of the lexicon modulate word recognition. More specifically, the number of words in the lexicon that share the same onset consonant as the target label, i.e. its cohort, and the number of words that differ from the target label in only one phoneme, i.e. its neighbourhood, dynamically modulate lexical activation.

Interestingly, the co-activation of phonologically similar words does not seem to be solely influenced by phonemic overlap. Mitterer (2011) tested adults' sensitivity to subtle sub-phonemic differences between words. In this study, the target label rhymed with the competitor label but differed in either voicing or place of articulation (one-feature distance) or in both voicing and place of the initial consonant (two-feature distance). The results show that subjects looked more often at the competitor in the one- than in the two-feature condition, suggesting that adults are sensitive to the sub-phonemic overlap between words (but see Ernestus and Mak 2004; Cole et al. 1978; Connine et al. 1997, that the effect of sub-segmental overlap is not necessarily linear during lexical access). Similarly, adults have been shown to exhibit graded sensitivity to subtle phonetic differences between words, such as within-category differences in voice onset time (McMurray et al. 2002), segmental lengthening (Salverda et al. 2003) and lexical stress (Reinisch et al. 2010).

Recent work on toddler word recognition has modified the visual world paradigm to examine questions such as whether toddlers implicitly generate the labels associated with visual images (Mani and Plunkett 2010b) and whether toddlers retrieve words that sound similar or mean similar things to a heard word during word recognition (Mani and Plunkett 2011; Arias-Trejo and Plunkett 2009). Such experiments typically present children with a name-known image in silence (the prime image) followed by the presentation of a target and a distractor image, where the label for the target image is either phonologically or semantically or phono-semantically related to the label for the name-known prime image. Looks to the target image are then monitored to examine whether children's fixations to the target image vary as a result of the relationship between the target and the prime image. Indeed, phonological priming studies using the visual world paradigm suggest that—similar to adults—upon seeing an image, children retrieve and activate not only the corresponding label for this image but also other words that sound similar to the label for this image (Huang and Snedeker 2010; Mani and Plunkett 2010a, 2011; Mani et al. 2012). The results of these studies are consistent with the following conclusions: Children possess phonologically detailed representations of words and are able to access this phonological detail and, importantly for the current chapter, automatically retrieve other words that are phonologically similar to a heard or implicitly generated word during word recognition. However, the definition of phonological similarity varies in these studies leaving open the question of both what exactly is meant when we suggest that children retrieve other words that are phonologically similar to a heard word during word recognition and also the levels of representations that are involved in such co-activation. In particular, what remains undetermined is the extent to which such co-activation of other similar-sounding words is driven by sub-segmental level overlap between phonologically similar words.

Given that toddlers appear to be sensitive to small changes to the phonological features of the phonemes of a word in word recognition tasks (White and Morgan 2008), one might assume that the co-activation of phonologically similar words during word retrieval and recognition is equally influenced by sub-segmental overlap. However, sensitivity to sub-segmental detail in detecting a deviant pronunciation of a word does not necessarily imply that such detail is routinely accessed in recognising correctly pronounced words or in retrieving the label of a visually presented name-known object. In other words: Is it the case that, upon hearing a word or seeing an object, words sharing greater sub-segmental overlap with the target word are more robustly activated relative to words with lesser sub-segmental overlap? This assumption would be in line with models of lexical processing, such as TRACE (McClelland and Elman 1986), assuming that word recognition is driven by feature-mediated access to the phonemes in a word: Activation on the feature level leads to activation of the corresponding phonemes, which in turn leads to activation of lexical tokens congruent with this input (Note that next to this bottom-up activation, top-down processes such as context restrictions might also influence language processing in toddlers, see Mani and Huettig 2012). However, there is little research investigating the degree of sub-segmental detail mediating lexical-level processing in toddlers. The current chapter will review the results of a study that attempts to address this issue by examining the degree to which sub-phonemic information mediates word retrieval and recognition by toddlers. First, however, we review the literature on sub-segmental effects in toddler word recognition.

2.1.1 *Phonological Feature Effects in Mispronunciation Detection Studies*

There is ample evidence that toddlers are sensitive to even subtle mispronunciations of familiar and newly learned words (Bailey and Plunkett 2002; Mani and Plunkett 2007; Swingley 2009; Swingley and Aslin 2000; among others).

This has been taken as evidence that children's lexical representations contain fine phonological detail. However, a growing body of research shows that children are not equally sensitive to all types of segmental mispronunciations. Mani and Plunkett (2010b) report that 12-month-olds show less sensitivity to voicing compared to manner and place changes (for similar findings with Dutch 20-month-olds see Van der Feest 2007). Similarly, Mani et al. (2008) show that 18-month-olds are more sensitive to roundedness changes to the vowels in words relative to height or backness changes. Altvater-Mackensen et al. (2014) show that certain place and manner changes are more readily detected by 18- and 24-month-olds than others, and results by Nazzi et al. (2009) suggest that consonantal and vocalic information might play a different role during lexical access in 30-month-olds (but see Mani and Plunkett 2007, 2010b; Mani et al. 2008). Taken together, these studies indicate that infants do not treat all changes to the sounds of words equally, which might suggest that they not only encode phonemic but also more fine-grained sub-segmental information in their lexical representations of familiar words.

Given that none of the studies discussed above systematically manipulated the degree of overlap between mispronunciation and correct pronunciations in terms of phonological features or sub-segmental content, these results could be explained by assuming that toddlers detect the difference between mispronunciations and correct pronunciations based on the segmental content. Nevertheless, there is evidence that the amount of sub-segmental overlap between a mispronunciation and a correct pronunciation of a word influences toddlers' sensitivity to mispronunciations: White and Morgan (2008) tested 19-month-olds' recognition of correctly pronounced or mispronounced familiar words including mispronunciations with a one-, two- or three-phonological feature change to the initial consonant. Results show that infants' looking behaviour is modulated by the amount of feature overlap shared by the initial consonant of the mispronunciation and the correct pronunciation, i.e. infants were most sensitive to three-feature changes to the consonants, less so to two-feature changes and least sensitive to one-feature changes. Furthermore, Mani and Plunkett (2010c) find that 24-month-olds are sensitive to sub-segmental overlap in vowel mispronunciations, although the size of the mispronunciation effect was modulated by the acoustic distance between the correctly and mispronounced vowels rather than by their distance in terms of phonological features. Both studies suggest that toddlers encode sub-segmental detail in their lexical representations—be it acoustic or feature information—and that they can use this detail to estimate the match between a heard (mispronounced) and a stored label.

While mispronunciation detection studies are invaluable in broadening our knowledge about the specificity of children's early lexical representations, they do not necessarily inform us (a) how much of this detail is used during lexical processing of correctly pronounced words, and (b) whether children access this detail when retrieving the label for a visually fixated name-known image.

A mispronunciation is, typically, not a word in the toddler's lexicon. Recognition of a mispronounced word, i.e. the detection of a mispronunciation, may invoke differential access to phonological detail relative to recognition of a correctly pronounced word. For instance, because toddlers know only very few minimal pairs, such as cat and hat, mispronunciations are usually non-words. Their recognition may, thus, invoke less top-down influence from the lexical level and greater bottom-up processing relative to the recognition of correctly pronounced familiar words or the retrieval of the labels of familiar objects. Second, recognising a mispronunciation involves toddlers' detection of a subtle difference between the heard mispronunciation and the stored representation of a familiar word. The correct pronunciation and the mispronunciation presumably trigger the same lexical representation (see Altvater-Mackensen and Mani 2013). This might invoke greater involvement from the lower levels of processing, such as the segmental or sub-segmental level, relative to situations in which toddlers have to recognise a match between a correctly pronounced word and its referent or in which they retrieve the label of a seen object without matching it to a heard word. Thus, toddlers' sensitivity to sub-segmental detail in mispronunciation detection tasks do not necessarily inform us about the extent of activation of sub-segmental information in the recognition of familiar, correctly pronounced words or in the retrieval of the label of a familiar object. A more appropriate tool to tap into the processes guiding activation of a lexical item and recognition of a word might be the phonological priming paradigm, which has been used successfully with toddlers in previous studies (Mani and Plunkett 2010a, 2011).

2.1.2 Effects of Phonological Overlap in Priming Studies

There are only few studies to date that investigate the processes underlying lexical activation in toddlers. These studies indicate that, upon hearing a word or seeing an image, toddlers activate not only the corresponding word itself but also other words that are semantically (Arias-Trejo and Plunkett 2009), phonologically (Mani and Plunkett 2010a, 2011) or phono-semantically related (Mani et al. 2012) to the heard word or the label for the image. Importantly, co-activation of words in the mental lexicon of toddlers is mediated by the phonological overlap between prime and target labels. For instance, Mani and Plunkett (2011) find that 24-month-olds' recognition of a target word, such as *ball*, is influenced by the previous presentation of an image displaying an onset-overlapping prime, such as *bed*. Similarly, Mani et al. (2012) find that 24-month-olds' recognition of a target word like *shoe* is facilitated by previous exposure to the prime *clock*. These findings are interpreted as evidence that presentation of the prime *clock* leads to activation of the similar-sounding sub-prime *sock*, which in turn leads to activation of the semantically related target *shoe*. Since the prime was only ever presented visually in these studies, the priming effect can only have arisen from the child internally generating the label for the familiar prime image and being sensitive to the phonological overlap between the prime and sub-prime label. This effect of phonological overlap between prime and target does not appear to be bound to the lexical status of the prime. Altvater-Mackensen and Mani (2013) found that auditory presentation of not only correctly but also mispronounced primes lead to facilitated recognition of words semantically related to the prime label in 24-month-olds. Thus, not only *sock* but also its mispronunciation *fock* leads to facilitated recognition of *shoe*.

These studies, however, only coarsely manipulated the degree of phonological overlap between prime and target; they either manipulated whether prime and target shared the initial consonant (Mani and Plunkett 2010a, 2011) or the rhyme (Mani et al. 2012; Altvater-Mackensen and Mani 2013). Interestingly, this seems to lead to different priming effects. While Mani and Plunkett (2010a, 2011) find that having the very same initial consonant hinders target recognition, rhyme overlap appears to facilitate target recognition (Mani et al. 2012; Altvater-Mackensen and Mani 2013; see Sect. 2.3.1. for a discussion of the different underlying processes). This has been taken as evidence that rhyme priming effects rely on the activation of the phonemes shared between the prime and the target (see also Radeau et al. 1995; Slowiaczek and Hamburger 1992), i.e. lexical activation is mediated by phonemic information in rhyme priming. However, neither of these studies manipulated the degree of overlap between prime and target in terms of phonological features or sub-segmental content, i.e. they do not investigate whether lexical activation of familiar words is mediated by sub-phonemic or only by phonemic information. Next, we present the results of a recent study addressing this question, namely, is phonological priming systematically modulated by the amount of sub-segmental overlap between the prime and the target?

2.2 Experimental Set-up and Results: Toddlers' Use of Sub-segmental Detail in Phonological Priming

We presented 32 monolingual German 24-month-olds with a visual priming task, where participants were presented with a prime image in silence followed by the simultaneous appearance of a target and a distractor image, and the label for the target image. The labels for the prime and target images rhymed with one another but differed on the initial consonant. The difference in the initial consonant was modulated across conditions, where this initial consonant of the prime-target labels differed in two phonological features, three phonological features, or four phonological features. Following linguistic theory, phonological features are the "building blocks" of phonemes that characterise their specific properties (e.g., Chomsky and Halle 1968; Clements 1985). For instance, features can be used to describe the place of articulation of a segment, such as [labial], [coronal] or [dorsal]. The phonological features contrasted in the current study included a segment's place of articulation, manner of articulation, voicing and nasality. We expected differences in toddlers' recognition of the target across the different conditions manipulating the degree of sub-segmental feature overlap between prime and target label. In particular, we predicted that target recognition should improve,

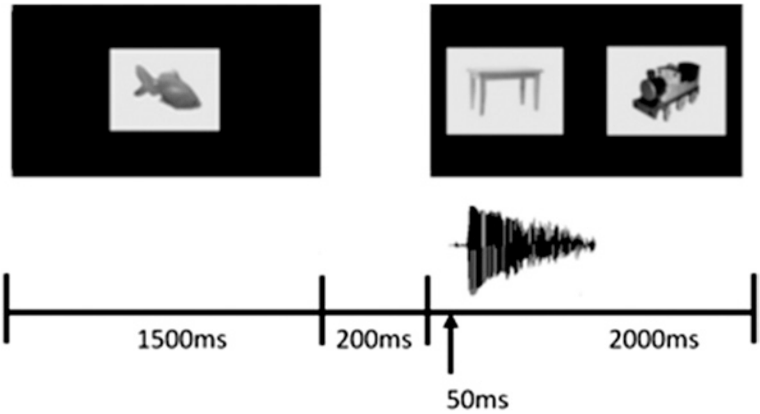

Fig. 2.1 Schematic of the trial structure. For instance, a related trial for the spoken target word Tisch ‘table’ displayed the image of a Fisch ‘fish’ (prime), followed by the side-by-side presentation of the images of a Tisch ‘table’ (target) and a Zug ‘train’ (distracter.) Original pictures were coloured

i.e. toddlers should fixate the target more, with increasing feature overlap between prime and target label. Note that using visual primes has a major advantage over using auditory primes: any priming effect that might occur necessarily involves the *lexical* activation of the prime label and cannot be attributed to pure acoustic overlap between a heard prime and target label because children have to internally generate the label for the prime image. Put differently, if we find that the priming effect is modulated by sub-segmental overlap between prime and target label, this would imply that retrieval of the prime label from the visual image entailed activation of sub-segmental detail associated with this label.

During each trial, children first saw a prime image presented in silence for 1500 ms, followed by a 200 ms inter-stimulus interval where the screen remained blank. Then target and distracter images appeared side-by-side on screen. Fifty ms following the appearance of the target and distracter images on-screen, i.e. 1750 ms into the trial, children were presented with the auditory target label. Target and distracter images stayed on-screen until the trial ended 2000 ms after the onset of the target label (see Fig. 2.1 for a trial schematic). This configuration of stimuli has proved successful in tapping into phonological effects in word recognition by 24-month-old toddlers (Mani and Plunkett 2011; Mani et al. 2012).

Each child saw four trials with a related prime and four trials with an unrelated prime. Prime, target and distracter were semantically unrelated, while we manipulated the phonological overlap between prime and target label. In related trials, prime and target rhymed and their initial consonants differed in two, three or four phonological features (see Table 2.1 for a stimulus list). The stimulus set was counterbalanced across children so that each child saw every target and distracter pair only once. We did not repeat primes or target-distracter pairs across trials to ensure that repetition effects did not distort results. The side on which the target and distracter appeared as well as the order of presentation of trials was

Table 2.1 Stimulus set

Prime		Target	Distracter
Unrelated	Related		
Haus 'house'	Buch 'book'(2: P, V)	Tuch 'scarf'	Eis 'ice'
Puppe 'doll'	Schuh 'shoe' (2: P, M)	Kuh 'cow'	Flasche 'bottle'
Hund 'dog'	Fisch 'fish' (2: P, M)	Tisch 'table'	Zug 'train'
Buch 'book'	Kamm 'comb' (3: P, M, V)	Lamm 'lamb'	Schwein 'pig'
Kamm 'comb'	Tasse 'cup' (3: P, M, V)	Wasser 'water'	Ohr 'ear'
Schuh 'shoe'	Puppe 'doll' (3: P, M, V)	Suppe 'soup'	Blume 'flower'
Tasse 'cup'	Haus 'house' (4: P, M, V, N)	Maus 'mouse'	Brille 'glasses'
Fisch 'fish'	Hund 'dog' (4: P, M, V, N)	Mund 'mouth'	Schrank 'closet'

Feature differences are listed in brackets (*P* place of articulation, *M* manner of articulation, *V* voicing, *N* nasality)

randomised. Since previous results with toddlers at 18 and 24 months of age show robust effects of phonological overlap between familiar words using similar procedures (Mani and Plunkett 2011; Mani and Plunkett 2010c), we expected that toddlers' looking behaviour will not only be influenced by the rhyme overlap between related prime and target, but also by subtler feature overlap in the initial consonant (see also White and Morgan 2008).

To estimate how children's looking behaviour was influenced by the phonological overlap between prime and target label, we calculated the amount of time that children spent looking at the prime (P), at the target (T) and at the distracter (D) throughout each trial. The proportion of target looking, T/(T + D), was calculated across the time-window from 300 ms after target word offset until the end of the trial. Trials in which children did not know the prime and/or the target label (according to individual vocabulary inventory reports filled out by the parents of the children) were excluded from analysis. Furthermore, only those trials in which children looked at least once at the prime picture in the prime phase of the trial, i.e. during the first 1500 ms, and in which children looked at least once at the target post-naming were included in the final analysis. All other trials were included in the analysis, as long as the child provided data for least 50 % of trials (3 children excluded).

Figure 2.2 shows the proportion of children's fixations at the target image every 40 ms in the trial separately for related and unrelated trials. As can be seen from the graph, children fixated the target more in related trials compared to unrelated trials, i.e. when the target was primed by an image whose label rhymed with the target label (related prime) compared to an image whose label was not related to the target label (unrelated prime). A paired-samples *t*-test on the mean proportion of target looking in the critical time-window 300 ms after target word offset confirmed a significant difference between children's target looking in related and unrelated trials ($t(28) = -2.198$, $p = 0.036$) with increased target looking in related trials: Target recognition was facilitated by the rhyme overlap between the labels for the prime and target image.

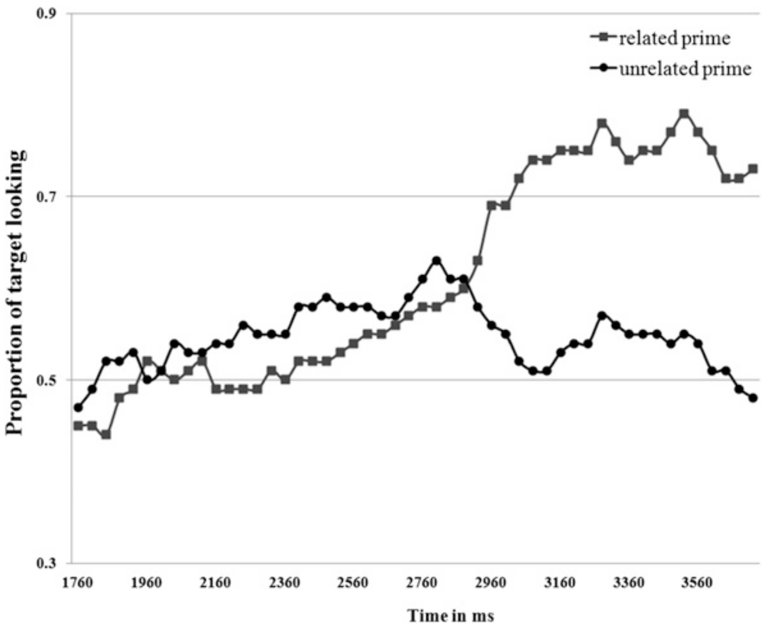

Fig. 2.2 Time course graph showing the mean proportion of target fixations in unrelated and related trials from target word onset (1750 ms) to the end of the trial

To further investigate the possible influence of feature overlap on the initial consonant of the labels for the prime and target image, we calculated the priming effect in the two-, three- and four-feature condition, i.e. the difference between target looking in related and unrelated trials, $[T/(T + D)]_{related} - [T/(T + D)]_{unrelated}$. If feature overlap modulates the priming effect, we expected to find an increase in the priming effect with increase in the amount of feature overlap in the initial consonant of the labels for the prime and target images. Figure 2.3 shows the mean difference in proportion of target looking in the two-, three- and four-feature conditions in the critical time-window after target word offset (i.e., 300 ms following target offset to the end of the trial).

As in White and Morgan (2008), we performed a trend analysis on the two-, three- and four-feature condition to examine the linearity of the effects of feature overlap. Similar to White and Morgan (2008), there was a linear trend in difference scores ($F(1, 59) = 3.495$, $p = 0.067$), but no quadratic trend ($p > 0.90$): Infants showed a larger priming effect with *increasing* feature overlap between target and prime label. This was further confirmed by a significant correlation between the size of the priming effect, i.e. the difference between target looking in related and unrelated trials, and the number of features changed ($r = -0.236$, $p_{(one\text{-}tailed)} = 0.03$). The size of the priming effect increased with increase in the degree of feature overlap between the prime and the target labels.

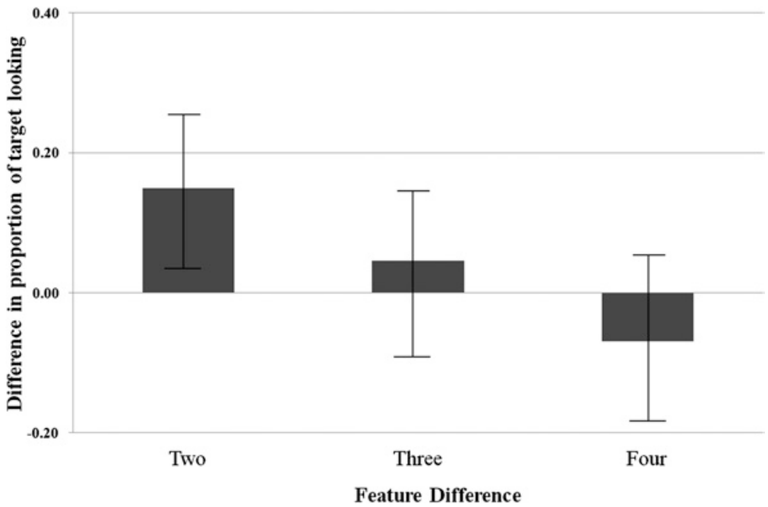

Fig. 2.3 Mean difference in proportion of target looking between unrelated and related trials after target word offset for two-, three- and four-feature distance (error bars: ±1 SE)

2.3 Discussion: Sub-segmental Detail Mediates Lexical Access in Toddlers

This chapter has provided a review of the literature on research examining toddler word recognition in the visual world paradigm as well as presented the results of a novel study examining whether toddlers' retrieval of the labels of familiar images and their recognition of correctly pronounced, familiar words involve access to the sub-segmental detail associated with the lexical representations of these words. In particular, we investigated whether the amount of feature overlap in the initial consonant between a prime and a rhyming target word modulates target word recognition. The results of this study provide evidence both for the facilitatory effects of rhyme overlap and for the activation of sub-segmental detail in toddlers' retrieval of the labels for visually presented images and recognition of familiar words.

2.3.1 Effects of Rhyme Overlap

Before we discuss the effects of sub-segmental overlap, let us first turn to the effect of rhyme overlap between words. Toddlers looked longer at the target following presentation of a visual rhyming prime relative to a prime with no obvious phonological relation to the target. This is an important finding since studies investigating phonological priming in toddlers have either focused on the effect of phonological overlap at the beginning—rather than the end—of words (Mani and Plunkett 2011), on semantically-mediated rhyme overlap (Mani et al. 2012) or on the effect of auditory non-word primes (Altvater-Mackensen and Mani 2013). Studies investigating phonological overlap at the beginnings of words show that an onset-overlapping prime interferes with target word recognition: toddlers' recognition of a target word is impaired following a prime overlapping in only the initial consonant with the target. In line with the adult priming literature, this finding is interpreted as evidence for lexical competition between words that start with the same consonant, i.e. belong to the same cohort (Mani and Plunkett 2011). In contrast to the interference effect observed in studies manipulating onset overlap, the current study finds that rhyme primes facilitate target word recognition in infants. This result is in keeping with effects of facilitated target recognition in semantically-mediated rhyme priming tasks in toddlers (Mani et al. 2012), e.g. experiments where the target (e.g., *shoe*) is semantically related to a rhyme competitor (e.g., *sock*) of the prime (e.g., *clock*); and previous studies showing that auditory non-word primes facilitate recognition of a rhyming target label (Altvater-Mackensen and Mani 2013). This result is also in keeping with results on rhyme priming in adults (see Monsell and Hirsh 1998, among others) showing that activation of a target is facilitated by previous presentation of a rhyming prime.

The different effects of onset and rhyme overlap in infants might be explained by suggesting that greater phonological overlap between prime and target aids recognition of the target: Target activation in priming tasks is sustained by the activation of the prime's phonemes because of the phonological overlap between prime and target (e.g., Radeau et al. 1995; Slowiaczek and Hamburger 1992). More specifically, when the child retrieves the prime label *Fisch* 'fish' upon seeing the picture of a fish, the corresponding phonemes /f/, /ɪ/ and /ʃ/ will be activated. The activation of the overlapping phonemes /ɪ/ and /ʃ/ in the target *Tisch* 'table' will aid subsequent activation and recognition of the target. The more overlap there is between the phonemes of the prime and the target, the more target recognition is facilitated by the prime. Note that facilitated activation of the target *Tisch* need not rely on the lexical activation of the prime *Fisch* itself in this scenario, but on the phonological-level activation that leads to the retrieval of the prime label. The interference effect observed for onset-overlapping primes, on the other hand, is typically interpreted as a consequence of the lexical-level activation of the prime that hinders activation of the target (e.g., Dufour and Peereman 2003; Segui and Grainger 1990). The different effects of rhyme- and onset-overlapping primes, thus, suggest that at least two different mechanisms modulate word retrieval and recognition in the developing lexicon: phonological-level effects that are modulated by the degree of phonological overlap between two retrieved words, and lexical-level effects that are modulated by the structure of the lexicon, i.e. the number of words in the toddler's lexicon that are phonologically similar to the retrieved words.

2.3.2 Effects of Sub-segmental Overlap

The focus of the study presented in this chapter was, however, whether retrieval and recognition of familiar words involves access to the sub-segmental detail associated with toddlers' representations of these words. Indeed, we found that the size of the priming effect did vary linearly with the amount of feature overlap; the smaller the feature overlap between the initial consonants of the prime and target, the smaller was the priming effect. Thus, the phonological priming effect was systematically modulated by the degree of sub-segmental overlap between the prime and the target label. While this resembles White and Morgan's (2008) finding of graded sensitivity to sub-segmental detail in mispronunciation detection in 19-month-olds, this result is a crucial extension of the White and Morgan findings and leads to the conclusion that both the implicit generation of the labels of visually fixated images and the recognition of correctly pronounced familiar words include access to the sub-segmental detail associated with toddlers' representations of these words.

We suggested earlier that toddlers' use of sub-segmental information in mispronunciation detection tasks does not necessarily imply the use of similar information in the recognition of a correctly pronounced, familiar word or in the implicit generation of the label of a visually fixated name-known object. In particular, we suggested that sub-segmental detail might be additionally called into play in mispronunciation detection since mispronunciations are, typically, not a word in the toddlers' lexicon and might call on more bottom-up resources relative to recognition of a word that is part of the toddlers' lexicon. The results presented in this chapter, however, show a similar influence of bottom-up sub-segmental information in toddlers' recognition of existing familiar words, i.e. words that are strongly associated with an entry in the toddlers' lexicon and for which top-down lexical-level processing may be expected to play a more dominant role. The similarity in the results of the current study and White and Morgan (2008) therefore raises questions with regard to the extent of top-down lexical-level processing in mispronunciation detection and suggests that mispronunciations trigger the lexical entries associated with the correct pronunciations (see also Altvater-Mackensen and Mani 2013, for more direct evidence that mispronunciations lead to lexical activation of the correct form of the target label).

The finding that toddlers' retrieval and recognition of familiar words involves access to the sub-segmental detail associated with the representations of these words is crucial to current models of language processing. Models of lexical processing such as TRACE (McClelland and Elman 1986) suggest that word recognition is driven by feature-mediated access to phonemes in a word. In particular, such models assume that the acoustic input leads to activation of the corresponding features at the feature level. This activation feeds through to the phoneme level so that phonemes congruent with the feature input are activated. Activation from the phoneme level then, in turn, leads to activation of lexical tokens congruent with this input. Since the prime was only ever visually presented in our task, our results further suggest that not only do toddlers rely on sub-segmental detail during auditory word recognition, but also retrieve sub-phonemic information when implicitly generating the label of an object present in the visual world around them.

Similar models of language processing have been called into force to explain the results of phonological priming studies to date (Mani and Plunkett 2011; Mani et al. 2012). However, previous phonological priming results could be explained without reference to feature-mediated lexical access given the overt phoneme overlap between the prime and the target in these studies, e.g. *Cat*-*Cap* versus *Cat*-*Book.* The results presented in this chapter, on the other hand, rely on different degrees of sub-segmental, but crucially non-phonemic overlap in the onset consonant of the prime and the target label. Therefore, the evidence reviewed in this chapter, more than other phonological priming studies to date, validate models of language processing that invoke sub-segmental or feature-mediated lexical access. Here, retrieval of the prime label leads to retrieval of the phonemes and the features corresponding to this label. Overlap between the target label and the prime label at the feature level leads to faster retrieval or processing of the target label in related trials relative to trials presenting no overlap between the prime and target label. In particular, the degree or amount of overlap in sub-phonemic features between the prime and the target label modulates the degree of the priming effect found in the current study. Note, however, that our results do not exclude an acoustic basis for toddlers' graded sensitivity to sub-segmental overlap. Mani and Plunkett's (2010c) results suggest that toddlers are sensitive to the acoustic rather than to the feature distance between words. While Mani and Plunkett's finding is based on children's responding to different degree of overlap in vowels, our finding is based on different degree of overlap in consonants. Acoustic distance in vowels can be captured in terms of formant frequencies, but identifying the relevant acoustic dimensions differentiating consonants is less straightforward. This makes them difficult to tease apart and evaluate against each other. Our findings, therefore, do not necessarily contradict an underlying acoustic basis for the current findings, inasmuch as we could not examine the influence of acoustic information on toddlers' responding in the current study. The results are therefore also compatible with models of word recognition proposing that lexical access is mediated by gradient acoustic—rather than feature and phoneme—similarity between the input and stored representations (e.g., Goldinger 1996).

2.3.3 Concluding Remarks

We have reviewed the literature on experiments using the visual world paradigm to assess infant word recognition, in particular, the amount of attention infants pay to phonological detail in word recognition. We have also presented a novel study using a modified version of the visual world paradigm to assess the extent to which toddlers access phonological detail when implicitly generating the label for a visually fixated image. The results of this study suggest that both the retrieval of an object's label and toddlers' recognition of a word involve activation of not only phonemic but also sub-segmental information associated with the lexical representation of this word. We therefore conclude that lexical access in 24-month-old toddlers is mediated by sub-phonemic information. It remains for future research to examine whether this sub-segmental content is feature-based or acoustic, perhaps by manipulating the degree of overlap at the vowel (where feature and acoustic content can be more easily separated from one another). These results have important implications for models of language processing, confirming as they do, that lexical access includes fine-grained analysis of the speech input into units of processing smaller than the phoneme.

A question that remains regards the degree to which sub-segmental information mediates lexical access at different stages of development. The adult literature is ripe with controversy with regard to the impact of sub-segmental information on word recognition in the fully developed lexicon (e.g., Cole et al. 1978; Connine et al. 1997; Ernestus and Mak 2004). Indeed, recent computational models suppose that sub-segmental information might have a larger impact on word recognition in the developing lexicon: Adapting TRACE (McClelland and Elman 1986) to model White and Morgan's (2008) data, Mayor and Plunkett (2014) show that graded sensitivity to sub-segmental detail during word recognition depends on the absence of inhibitory connections between words. Subtle effects of sub-phonemic overlap overtly impact word recognition only in small lexicons in which words do not inhibit each other during lexical access. In particular, Mayor and Plunkett predict that graded sensitivity to feature overlap will not be found in older children with sufficiently large vocabularies, since lexical inhibition effects are strengthened by increasing vocabulary size (see also Mani and Plunkett 2011; Arias-Trejo and Plunkett 2009). This does not imply that sub-segmental detail is no longer activated during lexical access. But, perhaps, once a critical mass of vocabulary knowledge is attained, lexical inhibition effects get strengthened to the extent that the perceptual similarity between words is no longer a simple linear function of overlapping features. At this stage, other factors, e.g. how *many* words overlap on certain phonological dimensions, may become more important.

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