Phonological Competition during Spoken-Word Recognition in Infants and Adults

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A Thesis presented for the degree of
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Dedicated To

Angela, Jürgen & Carla

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This thesis examines how phonological information mediates visual attention in adults and 2-year-olds. It makes use of the Visual World Paradigm during which participants see images on a screen and hear phonologically related or unrelated words in order to investigate the time course of processing of phonological information. It further examines how the amount of time observers are given to look at the images before hearing the spoken word (pre-naming time) and the concept of implicit naming (silent labelling of the images) modulate observers' processing strategies. Findings from Experiments 1-4 reveal that adults employ continuous processing strategies whereby different lexical entries compete with each other in parallel until the most relevant entry is selected. In contrast to previous findings (Huettig & McQueen, 2007), results from Experiments 1 and 2 show that adults' visual attention is mediated by phonological information even with a very short pre-naming time of 200ms suggesting that silent labelling of the images before hearing the auditory input is not required for this modulation. Experiments 3 and 4 demonstrate that when given a pre-naming phase, adults make use of processing strategies focusing on the first phoneme of words whereas without any pre-naming time, they rely more on processing strategies taking into account the overall similarity of words. Experiment 6 shows that while infants' visual attention does not seem to be mediated by phonological information when using real words - possibly due to the activation of lexical information - 2-year-olds seem to place greater importance on the overall similarity between words rather than on the onset of spoken words when presented with pseudowords. Continuous and incremental models of spoken-word recognition are contrasted and the role of implicit naming and the length of the pre-naming time is discussed in relation to these models. Finally, it is discussed how assumptions made by the Featurally-Underspecified Lexicon account (Lahiri & Reetz, 2010) might feed into the extension of continuous processing models such as the TRACE model (McClelland & Elman, 1986) (Experiment 7).

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Chapter 1

Introduction

1.1 Language-Mediated Visual Attention

It has long been established that language can drive our visual attention. Cooper (1974) was one of the first who showed that when presenting participants with an array of pictures, they would automatically fixate any objects that were named or related to a spoken word they heard. Later research established that adults look at objects that may either be phonologically related to the spoken word (e.g. *ham* - *hat*) (Allopenna et al., 1998; Huettig & McQueen, 2007; Chow et al., 2017), semantically related (e.g. *fork* - *spoon*) (Huettig & Altmann, 2005; Yee et al., 2009; Chow et al., 2017) or visually related (e.g. *snake* - *rope*) (Dahan & Tanenhaus, 2005; Huettig & McQueen, 2007; Huettig & Altmann, 2007). While it is well established that visual, semantic and phonological information compete with each other during

language-mediated visual attention, there is still a lack of understanding regarding how exactly phonological information is processed during spoken-word recognition when observing a visual display. Furthermore, while these processes have been investigated to some extent in adults, less research has been conducted concerning phonological competition during language-mediated visual attention in infants. This thesis will therefore focus on how phonological features drive infants' and adults' visual attention during spoken-word recognition and how this may be related back to theories of spoken-word recognition.

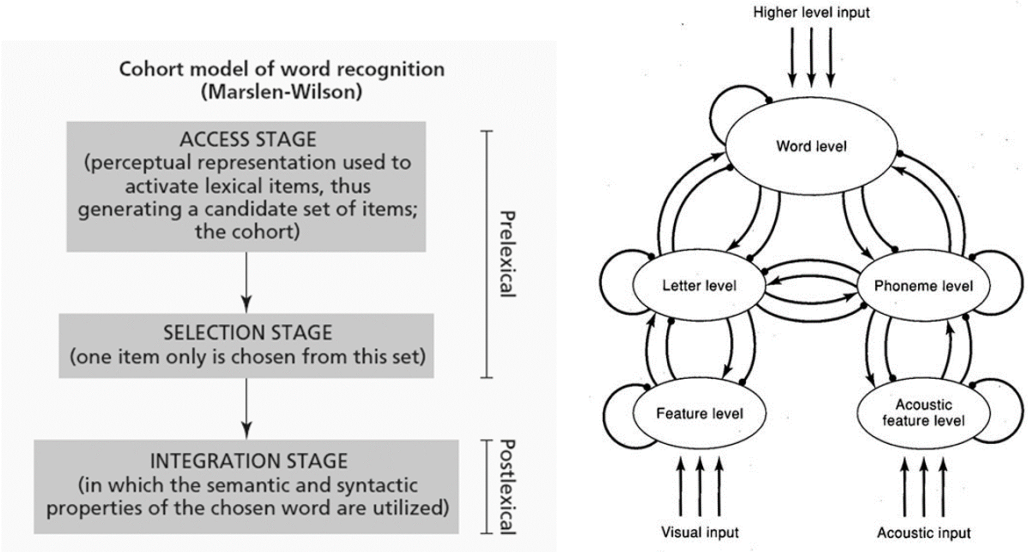
1.2 Theories of Spoken-Word Recognition

A number of studies have investigated the way in which words create competition during spoken word recognition and two alternative accounts have been proposed trying to explain these processes. Some researchers have proposed that spoken words are processed and integrated in a continuous manner (Allopenna et al., 1998) and that partially matching words compete with each other until one of them is selected (e.g. TRACE, (McClelland & Elman, 1986)). This account suggests that various lexical candidates are activated in parallel and compete through inhibitory and excitatory connections. Theories of spoken-word recognition can be examined by analysing participants' looking proportions to objects whose names sound similar to words

they hear. Models such as TRACE (McClelland & Elman, 1986) assume that looking proportions to objects should be correlated with the degree of lexical overlap between the name of the visual object and the spoken word. TRACE therefore predicts that not only words that start with the same phoneme as a spoken word are activated as possible candidates throughout unfolding of the auditory word, but that also words which rhyme with the auditory word become activated as possible candidates. This suggestion is supported by evidence that we are able to correctly recognise words that contain mispronunciations.

In contrast, theories such as the cohort model (Marslen-Wilson, 1987) suggest that spoken-word recognition is incremental. Marslen-Wilson (1987) claims that word recognition is based on various bottom-up processes while also allowing contextual information to influence word recognition. The cohort model suggests that upon hearing the initial sounds of a word, a set of possible candidate words starting with the same phoneme is activated. Such candidate words are gradually excluded as the rest of the word is revealed until only the correct match is left as a possible candidate. Support for the cohort model comes from findings of lexical decision tasks. For instance, Marslen-Wilson & Zwitserlood (1989) used a cross-modal priming technique to show that rhyme words are less effective primes in a lexical decision task than the complete word. While the cohort model claims that higher-level contextual assessment does take place, such top-down processes cannot influence initial access such as activation of "perceptual struc-

tures in the recognition lexicon" (p.79, Marslen-Wilson (1987)). The cohort model therefore conflicts with interactive activation models like TRACE (McClelland & Elman, 1986) that allow top-down processes to influence very early access. According to the cohort model, words that contain mispronunciations - particularly in the beginning of the word - should be excluded as possible candidates early on. Models such as the TRACE model therefore are better able to account for our ability to recognise words containing mispronunciations. For a visual depiction of incremental models such as the Cohort model and continuous processing models, see Figure 1.1.



(a) Cohort model. (b) TRACE model.

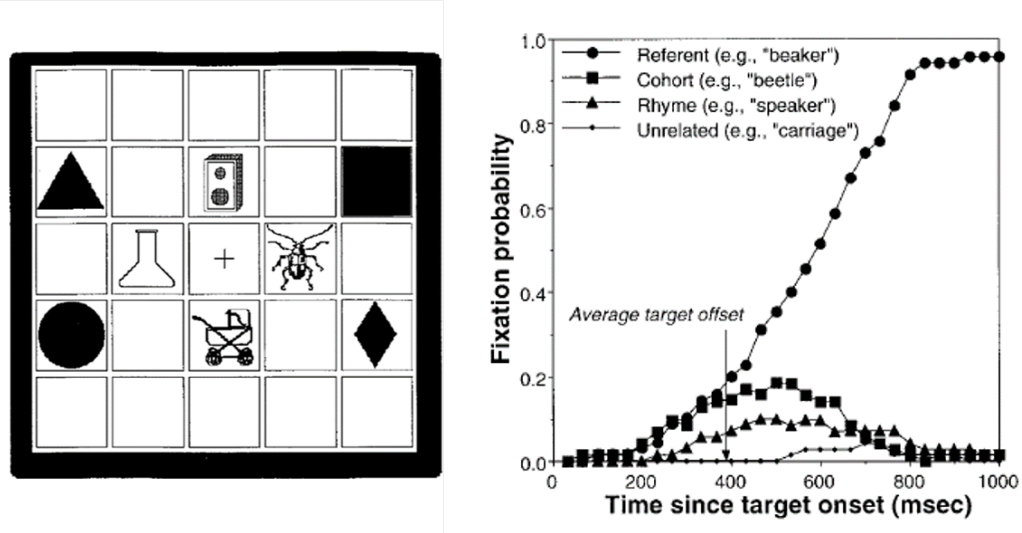
Figure 1.1: Examples of incremental (Cohort model (Marslen-Wilson, 1987)) and continuous (TRACE model (McClelland & Elman, 1986)) models of spoken-word processing.

1.3 The Visual World Paradigm

The Visual World Paradigm (VWP) (Cooper, 1974) is a common technique used to examine language processes in both children and adults and a great number of studies have made use of this paradigm in order to investigate theories of spoken-word recognition. During this procedure, participants listen to auditory input while looking at visual scenes that may be related to the auditory input. Tracking participants' eye movements in such a setup allows making inferences about their ongoing cognitive processes without requiring them to make active responses. This makes it a particularly desirable design for infants who are too young to give responses such as speaking, pressing buttons or pointing at objects. It is, however, also used with adults since it allows examining the timing with which visual attention unfolds and is driven by spoken words: Using the VWP one can investigate at which point in time during the unfolding of a spoken word attention is directed towards words and objects that are, for instance, phonologically related to the spoken word to varying degrees (Huettig et al., 2011). Such phonologically related objects could, for example, be objects who's phonological codes rhyme with the spoken word (rhyme competitor, e.g. *coat* - *boat*) or whose phonological code starts with the same phoneme as the spoken word (onset competitor, e.g. *coat* - *cup*).

1.4 Spoken-Word Recognition in Adults

In a classic experiment using the VWP, Allopenna et al. (1998) investigated the influence of word similarity on competition between two words during natural speech recognition. They recorded eye movement behaviour while participants listened to instructions to place one of four pictured objects in a certain position (*target*, e.g. beaker). Names of the distractor objects either shared the same onset and vowel as the target object (*onset* competitor, e.g. beetle), rhymed with the target object (*rhyme* competitor, e.g. speaker) or were completely unrelated (*unrelated* distractor, e.g. carriage). The authors found that considerably more fixations were made to *onset* and *rhyme* competitors than to unrelated objects. Furthermore, fixations to *onset* competitors started earlier and had a higher peak compared to *rhyme* competitors. These findings therefore imply that even partially matching words that do not share an onset with the target word can create competition that increases fixations to *rhyme* competitors. For an example of the setup used in this study, see Figure 1.2a, and for an overview of the results, see Figure 1.2b. Allopenna et al. (1998) further showed that looking behaviour in their experiment resembled simulations made by the TRACE model (McClelland & Elman, 1986) and therefore provided evidence for continuous models of spoken-word recognition.



(a) Setup. (b) Results.

Figure 1.2: Setup and results for original study by Allopenna et al. (1998).

Huettig & McQueen (2007) investigated the time-course of looking to visual, semantic and phonological distractors when presenting adults with a four-picture display. Dutch participants were instructed to look at one of four objects in a visual display. One of the objects was a visual distractor meaning that it had a similar shape as the target object. Another object was semantically related to the target object while the third object was phonologically related to the target meaning it started with the same consonant. The last object was completely unrelated to the target object. The authors found that when the visual display appeared together with the spoken word, fixations were first made to phonological distractors followed by fixations to visually and semantically related distractors. However, when the visual display only appeared 200ms before the onset of the target word, no increase

in fixations to phonologically related distractors could be found while fixation probabilities for visually and semantically related distractors still increased starting from approximately 400ms after the onset of the auditory word. When replacing the pictures of objects with their printed names, fixation probabilities were increased for phonologically related distractors but not for visually- or semantically-related distractors. These findings indicate that semantic, visual and phonological information is retrieved in a cascaded manner, first activating phonological information followed by visual and semantic information. Furthermore, these results suggest that retrieval of such information is dependent on the way visual input is presented in a visual world paradigm (e.g. timing of the stimulus presentation and whether presenting images or written words).

Taken together, these studies suggest that spoken-word recognition in adults may be both incremental and continuous. Spoken word onsets seem to lead to quick and high activations of words that start with the same phoneme, however, the remaining parts of the spoken word can also lead to the activation of other phonologically related words such as rhymes (Allopenna et al., 1998).

1.5 Spoken-Word Recognition in Infants

While the above studies have investigated phonological competition during spoken-word recognition in adults, less research has examined

these competition effects in infants. It is possible that infants use different processing strategies as compared to adults since their lexicon has not fully developed yet. Some strategies used by adults may in fact impede learning of new words in infants. For instance, infants may make less use of incremental processing strategies since rejecting lexical candidates simply based on word onset information may hinder them from considering the possibility that they are encountering a word which is not yet part of their lexicon (Walley, 1993).

1.5.1 Infant Preferential Looking Studies

In an early study, Fernald et al. (1998) demonstrated that 2-year-old infants display language-mediated visual attention similar to the behaviour previously shown in adults (Cooper, 1974). They presented infants with two pictures that were shown simultaneously for four second after which one of the displayed objects was then labelled. Infants had a further 5 seconds to look at the named object after target word onset. In such a preferential looking paradigm, 2-year-olds typically started fixating the target object approximately 680ms after onset of the target word.

Swingley et al. (1999) were one of the first to investigate the time course of speech processing in infants trying to examine whether infants process speech continuously as had been shown in adults previously (Allopenna et al., 1998). Based on the method used by Fernald et al. (1998), 2-year-old children were presented with two pictures. The

two pictures were either phonologically unrelated to each other (*no overlap* condition) or had overlapping onsets (e.g. tree - truck, *overlap* condition). As previously, the pre-naming phase lasted four seconds and infants then had 5 seconds to look at the object after target word onset. Response latencies of fixating the target after fixating the distractor were significantly longer for the *onset overlap* condition as compared to the *no overlap* condition. These findings suggest that the presence of an *onset* competitor makes it more difficult for infants to reject this competitor as a possible word candidate. Visual attention of 2-year-old infants thus seems to already be modulated by phonological competition. Swingley et al. (1999) further interpret these findings as evidence for incremental processing of the speech signal in 2-year-olds. In a second experiment, the authors compared response latencies to target words in *no overlap* and *rhyme-overlap* conditions. In the *rhyme-overlap* condition, the labels for the two objects presented were *rhymes* and only differed in their onset. Response latencies did not differ in the two conditions suggesting that the presence of a *rhyme* distractor did not delay recognition of the target object. This further suggests that 2-year-old infants process words incrementally, unlike adults who had previously been found to make use of continuous processing strategies (Allopenna et al., 1998). However, an alternative explanation for a lack of increased response latencies in the *rhyme-overlap* condition could be the use of target present trials. It is possible that the presence of the target object may have overshadowed a potentially small *rhyme* effect. One way of investigating this idea is to present rhyme competitors in a

target absent design in which the spoken word does not fully match any of the objects presented. This idea is supported by findings by Chow et al. (2015) who showed phonological and taxonomic activation in 2-year-old infants in a target absent but not in a target present design, presumably due to the strong competition created by the target object.

1.5.2 Infant Priming Studies

Mani & Plunkett (2010) investigated phonological competition in 18-month-olds using a picture-based phonological priming technique. Infants were presented with the picture of a prime for 1.5 seconds which was followed by a blank screen for 200ms. They were then shown another two pictures for 2050ms. On related trials, the label for one of the pictures had the same first phoneme as the label for the prime picture. The other picture was phonologically unrelated to the prime. On unrelated trials, both pictures were unrelated to the prime. 50ms after the onset of the visual presentation of the two pictures, infants were presented with the auditory label for one of the two pictures, instructing them to look at that picture. The authors found that infants spend more time looking at the target picture on primed trials as compared to unrelated trials. These results suggest that 18-month-olds are already capable of detecting phonological relatedness. Importantly, the prime picture was never labelled during the experimental procedure, leading to the conclusion that infants must have silently labelled the pictures. However, the mechanisms underlying these results remain unclear. It is

possible that the related prime facilitated looking at the target picture or that the unrelated prime lead to an interference with looking at the target picture.

In a subsequent study, Mani & Plunkett (2011) used the same picture-priming technique with the same stimuli in order to investigate phonological competition in 24-month-olds. In contrast to findings from 18-month-olds, the authors found that target recognition was inhibited in 24-month-olds when primed with a phonologically related picture as compared to phonologically unrelated pictures. Furthermore, they demonstrated inhibition effects for related primed trials as compared to unprimed trials. Finally, neighbourhood size of the target word influenced this inhibition: targets with a small neighbourhood size lead to an increased time infants spent looking at the target than large neighbourhood sizes. Altogether, these findings suggest that 18-month-olds as well as 24-month-olds implicitly name unlabelled primes in a visual world paradigm. By the age of 24 months, infants' lexicon seems to be structured according to phonological similarity allowing phonologically related words to become activated and compete during word recognition.

Additionally, Mani et al. (2012) demonstrated that 2-year-old infants were faster at word recognition when the word was preceded by a phono-semantically related prime as compared to an unrelated prime. Phono-semantic primes are words which are phonologically related to a word that is semantically related to the target word. For instance, *nose*

is phono-semantically related to *cheese* due to the word *cheek* which is semantically related to *nose* and phonologically related to the word *cheese*. Importantly, Mani et al. (2012) found these phono-semantic priming effects for both onset as well as rhyme primes suggesting that either type of phonologically related competitor can modulate subsequent spoken-word recognition in 2-year-olds.

Finally, some evidence suggests that processes related to phonological processing of spoken words may change between the ages of 24 and 30 months. For instance, Angulo-Chavira & Arias-Trejo (2018) conducted a study investigating phono-semantic activations in toddlers. They presented 24- and 30-month-old infants with an unlabelled prime image which was followed by the presentation of a target and a distractor. In one experiment, infants saw a prime that was followed by a semantic-phonological distractor – i.e. a distractor which had a phonological relationship to a word that was semantically related to the prime (e.g. dog-cat-cup). In a second experiment, the prime was followed by a distractor which had a phonological-semantic relationship to the prime (e.g. cup-cat-dog). Results showed that both age groups displayed phono-semantic priming effects whereas semantic-phonological priming effects were only observed in 30-month-olds. These findings suggest that there may be a shift in semantic-phonological processing between the age of 24 and 30 months.

1.5.3 Infant Visual World Paradigm

While there are some studies which examined phonological competition in toddlers using preferential looking or priming studies, there is a lack of studies which have investigated phonological competition during spoken-word recognition in infants using the VWP.

Recently, Chow et al. (2017) used a target absent visual world paradigm with infants to investigate competition between phonological and semantic/taxonomic distractors during spoken-word recognition. The authors presented 2-year-olds with four images out of which one started with the same sound as the spoken word while another one was either semantically or taxonomically related to the spoken word. Furthermore, there were two distractors that were visually, phonologically and semantically unrelated to the target word. Showing the images to infants for four seconds before the onset of the spoken word, the authors found that infants looked more at the *onset* distractor than the unrelated distractors in a time window between approximately 330 and 1000ms after word onset. These results confirm previous findings by Swingley et al. (1999) that language-mediated visual attention in 2-year-olds can be guided by words that share the same onset as images presented on a screen. As part of a doctoral thesis, Chow et al. (2015) further presented infants with *onset* as well as *rhyme* competitors in a VWP and found early increased looking proportions towards the *onset* competitor followed by later and longer lasting looking proportions towards the *rhyme* competitor as compared to *unrelated* distractors. This pat-

tern resembles looking behaviour by adults in Allopenna et al. (1998)'s classic experiment and would indicate that infants make use of continuous processing strategies such as suggested by the TRACE model (McClelland & Elman, 1986). Such findings are in contrast to previous findings by Swingley et al. (1999) who did not find any effects of *rhyme* competitors and therefore suggested that infants may be using more incremental processing strategies.

Altogether, these studies suggest that infants show phonological competition during spoken-word recognition in a visual world paradigm. Furthermore, they imply that while infants are sensitive to *onset* competitors, it is unclear if and under which conditions they are sensitive for *rhyme* competitors. There is reason to believe that these processes differ between adults and infants who still have a limited vocabulary size and rely on being able to learn new words. Some researchers (Walley, 1993) suggest that infants may be less likely to use incremental word recognition as this would complicate learning of new words: If infants rejected lexical candidates simply based on word onset information, they would reject the possibility of a new word that is not part of their lexicon yet. Finally, there is some evidence suggesting that processes related to phonological processing may change between the age of 24 and 30 months (Angulo-Chavira & Arias-Trejo, 2018).

1.6 Implicit Naming and the Pre-naming Phase

As mentioned above, there has been evidence suggesting that the way different phonological competitors compete for adults' attention may be influenced by the amount of time they are given to look at objects before hearing a target word (Huettig & McQueen, 2007). This may be due to the phenomenon of implicit naming whereby observers silently generate the phonological code of objects presented in a visual world paradigm before hearing the target word. This silent labelling happens without participants speaking the words out loud and the phonological code generated this way can then influence processing of subsequent spoken words. Zelinsky & Murphy (2000) have shown that participants implicitly label objects even when a task does not require them to do so and even though the naming of a picture takes approximately 500ms, partial encoding of its phonological code may already be achieved after a much shorter time (Humphreys et al., 1988). This is particularly relevant if one assumes cascaded processing of picture identification. Even though this implicit naming can take place, it may not be an automatic process meaning that objects' names aren't always retrieved as soon as they appear on a screen - participants may alternatively encode visual information such as shape or colour rather than the phonological code (Dahan & Tanenhaus, 2005). This has lead to two different hypotheses on how picture-word matching is achieved during language-mediated

visual attention in a visual world paradigm.

The implicit naming account suggests that participants implicitly label all images they are presented with and then match these generated phonological codes to the incoming auditory input. Observers may then, for example, fixate more on the picture of a pen when hearing the word "pear" due to the partial match in the beginning of these two words. An alternative process of matching the spoken word and the pictures could be that by extracting the phonological representation of the auditory input, various phonological neighbours are also activated together with their respective semantic and visual representations. Therefore, when hearing the word "pear", its phonological neighbour "pen" might also become activated, increasing looking proportions to the picture of a pen. Huettig & McQueen (2007) showed that adults only fixated more on phonologically related than unrelated objects when they were given more than 200ms to preview the images before hearing the target word, supporting the implicit naming account of picture-word matching.

There has been ample evidence suggesting that observers do in fact implicitly name objects they encounter even when not required to do so and that such labelling modulates subsequent spoken-word recognition.

1.6.1 Evidence from Visual Search Paradigms

Adults have previously been found to activate the phonological code of objects upon seeing them in a visual search context. For instance, Meyer et al. (2007) used a visual search paradigm in which participants

were first presented with the picture of a prime and then with a search display containing four objects. Participants had to indicate whether the prime object was present in the search display. The authors found that if one of the objects in the search display was a homophone of the prime object (e.g. *boy* - *buoy*), response latencies increased while fixations towards the target decreased. Crucially, none of the objects were labelled during the experiment, leading to the conclusion that participants must have silently labelled prime and distractor objects which resulted in an increase in attention towards phonologically related distractors. However, for this study, participants were familiarised with the objects and their respective labels prior to the experiment. A study by Görges et al. (2013) who aimed at replicating these findings in German found that such competition effects could only be found if participants had been introduced to the objects and their respective labels prior to the experiment. These effects were found regardless of whether the target object was presented as a picture or in its written form. However, they failed to find any effects when participants were not familiarised with the material prior to testing. These results suggest that the way in which objects are first introduced has an impact on subsequent competition effects between phonologically related objects.

1.6.2 Evidence from Picture-Picture Interference Paradigms

Using a picture-picture interference paradigm, Morsella & Miozzo (2002) investigated whether the phonological code of to-be-ignored distractors may influence naming of phonologically related objects. For this purpose, they presented participants with two superimposed pictures, one displayed in green and the other in red. Participants were instructed to ignore the picture of one colour while naming the object of the other colour. Participants were better at naming the target object on trials where the distractor was phonologically related to the target. These findings suggest that participants may have retrieved the phonological code for the distractor images and that this code in turn influenced picture naming of the target object. Jescheniak et al. (2009) tried replicating these findings in the German language. However, they failed to find any facilitation effects when presenting participants with two overlapping pictures. They did, however, find facilitation effects when presenting overlapping objects with their corresponding written labels. These results question the idea that seeing the picture of an object automatically leads to activation of the phonological code for this object.

1.6.3 Implicit Naming in Infants

While the phenomenon of implicit naming is well established in adults, there are also studies suggesting that infants implicitly name objects and that this labelling impacts following word recognition. For instance, priming studies described earlier have demonstrated that presenting 2-year-old with unlabelled images modulates recognition of following phonologically related objects (Mani & Plunkett, 2010, 2011).

More recently, Styles et al. (2015) used an ERP design in which they presented 14-month-olds with pictures of objects which were complemented with their respective auditory labels after 1000ms. The authors found differences in EEG responses for objects for which infants knew their respective auditory label as compared to nameless objects: Name-known objects lead to short-lasting negative-going deflections in the frontal, left centro-temporal and left occipital regions approximately 126-225ms after picture onset. Furthermore, there was a positive deflection over the right centro-temporal regions approximately 420-720ms after picture onset. These findings suggest a difference in processing of pictures for which infants know their respective auditory labels as compared to nameless objects. Such results imply that infants may have retrieved the phonological code for the objects and suggest that linguistic processes played a role when infants were simply looking at a picture.

Finally, 21-month-old infants seem to not only silently label objects for which they know the label but don't produce it yet, but they seem

to be also able to put words of differing lengths in different categories when encountering unlabelled objects. Ngon & Peperkamp (2016) used an anticipatory eye movement method to demonstrate that 21-month-old infants could categorise monosyllabic and trisyllabic labels when presented with objects which were not labelled and for which they knew the labels even though they were not producing them yet.

Altogether, the above studies suggest that adults as well as infants retrieve the phonological code for objects when they are simply looking at them and that this implicit naming process influences following word recognition.

1.7 Models of Multimodal Word Recognition

A range of models also looks more closely at the interplay of extra-linguistic factors such as visual and semantic cues. For example, Smith et al. (2017) recently extended the original TRACE model (McClelland & Elman, 1986) to allow visual and semantic information to influence spoken-word recognition at the lexical level. This extension has been referred to as the TRACE+ model (Smith et al., 2017) and represents a multimodal interaction model in which multimodal information can interact with phonetic features, phonemes and words at the lexical level. Furthermore, Smith et al. (2017) present the Multimodal Integration Model (MIM) which suggests that there may be a central hub which

integrates information from different modalities. A crucial difference between the TRACE+ and the MIM entails that TRACE consists of a pre-defined hierarchy, namely phonetic features, phonemes and words at which integration can occur up or down the hierarchy. Within the MIM, on the other hand, no assumptions are made regarding information flow.

While simulations from TRACE+ and MIM are able to account for looking-behaviour towards rhyme competitors in a visual world paradigm, their main purpose is to explain multimodal integration of visual, semantic and phonological information. However, the current thesis is less concerned with the interplay of information coming from different modalities and instead aims to focus on phonological competition created during spoken-word recognition. One model that looks more closely at the way in which activation of certain phonemes can lead to activation of neighbouring phonemes and vice versa is the Featurally-Underspecified Lexicon (Lahiri & Reetz, 2010) which will be described in the following section.

1.8 The Featurally-Underspecified Lexicon

Continuous processing models such as the TRACE model (McClelland & Elman, 1986) suggest that upon hearing spoken words, various lexical candidates are activated in parallel and compete with each other

through inhibitory and excitatory connections. They propose that activation of one phoneme also leads to activation of similarly sounding phonemes through these excitatory connections. No claims are, however, made regarding whether these connections differ in strength depending on their connection. They rather assume that one phoneme will activate another one with the same strength as an activation in the opposite direction.

However, alternative linguistic theories suggest that the strength of these connections indeed differs depending on the direction in which phonemes activate each other. One such theory is the Featurally-Underspecified Lexicon account (FUL, Lahiri & Reetz (2010)) which suggests that the strength of these activations differ in particular regarding coronal/non-coronal phonemes. In order to understand this concept, one should note that English consonants are distinguished regarding their place and manner of articulation and whether they are voiced or unvoiced. The place of articulation is further subdivided into coronal and non-coronal phonemes. Coronal phonemes are produced using the flexible front part of the tongue while non-coronals are produced without raising this part of the tongue. The FUL (Lahiri & Reetz, 2010) suggests that there is an asymmetry in adults' representations of these coronal and non-coronal features. More specifically, it claims that while non-coronals can activate other non-coronals as well as coronals, coronals themselves are only able to activate other coronals. If the assumptions made by FUL are correct, then simulations made

by continuous processing models such as TRACE are not entirely accurate since they do not distinguish between coronal phonemes activating non-coronal phonemes and activations in the opposite direction. It is therefore possible that such models may need to be extended in order to account for varying strengths with which different phonemes can activate each other.

1.9 Thesis Overview

The aim of this thesis was to investigate the time course of phonological competition during spoken-word recognition in infants and adults. Investigating this time course allows examining whether spoken-word recognition happens continuously or in an incremental manner and whether these processes differ between infants and adults. Identifying differences and similarities between 2-year-olds and adults in the way phonological competition modulates spoken-word recognition lays a first foundation upon which future research may examine how any differences detected may shift during development.

The **Introduction** chapter presents an overview of language-mediated visual attention, the Visual World Paradigm and theories of spoken-word recognition. Research in the field of spoken-word recognition for adults and infants is reviewed and implications for the underlying theories and processes are summarised. The concept of implicit naming and its possible interaction with spoken-word recognition are discussed. Fi-

nally, the Featurally-Underspecified Lexicon is introduced as a possible extension to continuous theories of spoken-word recognition.

Experiment 1 demonstrates an attempt at developing a study similar to Allopenna et al. (1998)'s adult experiment for 2-year-old infants. For this purpose, infants were presented with four images in a visual world paradigm and heard an accompanied sentence instructing them to look at an object that was not among the images displayed (target absent design). Among the four images was one object who's phonological code started with the same phoneme as the spoken word (onset competitor), one object that rhymed with the spoken word (rhyme competitor) and two objects that were phonologically unrelated to the spoken word. A target absent design was employed since previous research has shown that target present designs in infants lead to strong looking proportions towards target objects, overshadowing possible phonological effects. It was expected that, if infants employ continuous processing strategies similar to adults, they should display early increased looking proportions towards the onset competitor followed by later and longer lasting increased looking proportions towards the rhyme competitor as compared to unrelated distractors. In order to compare infant and adult looking behaviour, the same experiment was run with adults. Importantly, participants were only given 200ms to look at the images before hearing the spoken word in order to investigate suggestions made by Huettig & McQueen (2007) that 200ms pre-naming time are not sufficient to elicit phonological effects during spoken-word recognition. If

the claims by Huettig & McQueen (2007) are replicable, then observers should display no preference towards phonological competitors over unrelated distractors under these conditions.

Experiment 2 examined whether using line drawings rather than real photographs may modulate observers' looking proportions towards phonologically related competitors. For this purpose, Experiment 1 was replicated in adults only replacing photographs with line drawings of objects. It was predicted that this would lead to a decrease in observers' preference for phonologically related competitors over unrelated distractors due to the idea that observers take longer to retrieve information from line drawings than photographs. Such findings would provide a possible explanation why Huettig & McQueen (2007) did not find any phonological effects in adults with a pre-naming time as short as 200ms when using line drawings.

Experiment 3 investigated whether increasing the pre-naming time and presenting different types of phonological competitors on separate trials in order to reduce the competition between them might increase looking proportions towards phonological competitors for both infants and adults. It was predicted that allowing both infants and adults more time to look at the images before hearing the spoken word might allow them to implicitly name all objects prior to hearing the spoken word. This may in turn facilitate competition to be generated by competitors that are phonologically related to the spoken word and therefore increase looking proportions towards such competitors. Furthermore, it

was predicted that by presenting onset and rhyme competitors on separate trials, competition between the two types of phonologically related competitors would be reduced preventing looking proportions towards onset competitors to overshadow looking proportions towards rhyme competitors. Such a setup should therefore lead to stronger rhyme effects than observed in Experiment 1.

Experiment 4 aimed at investigating whether adults still show a preference for phonologically related competitors over unrelated distractors when they are given no time to look at the images before hearing the spoken word. This was done in order to disentangle whether the significant *rhyme* effects observed in adults in Experiment 3 were due to the increased pre-viewing time or due to separating *onset* and *rhyme* competitors. For this purpose, Experiment 3 was replicated with adults only. However, images of objects were presented immediately after participants had heard the entire spoken word. It was predicted that, if implicit naming is not required for a preference for phonologically related competitors, then looking proportions towards phonologically competitors should still be increased as compared to unrelated distractors under this setup.

Experiment 5 was a replication of a study previously run at the Oxford BabyLab (Chow et al., 2015) which had demonstrated looking behaviour resembling simulations from continuous processing models in 2-year old infants. For this experiment, infants were presented with an auditory word and four images which included one onset competitor,

one rhyme competitor and two unrelated distractors. It was expected that this replication would show similar results as previously demonstrated whereby infants would display early increased looking proportions towards onset competitors followed by later and longer lasting increased looking proportions towards rhyme competitors.

Experiment 6 explored the hypothesis that using real words in a visual world paradigm may engage infants' lexicons in a way that may overshadow more subtle phonological effects. For this experiment, infants were presented with four images immediately after they heard a spoken pseudoword. The four images included one onset competitor, one rhyme competitor and two unrelated distractors. If real words do indeed lead to lexical information overshadowing phonological effects, then it would be expected that infants show increased looking proportions towards both phonological competitors with this pseudoword setup. Furthermore, if infants make use of continuous processing strategies, their looking behaviour should resemble simulations from models such as TRACE (McClelland & Elman, 1986) whereby they display early increased fixations towards onset competitors followed by a later and longer lasting increase in looking proportions towards rhyme competitors.

Experiment 7 investigated whether coronal and non-coronal phonemes activate each other with differing strengths depending on the direction of activation as suggested by the Featurally-Underspecified Lexicon (Lahiri & Reetz, 2010). For this purpose, adult participants

were presented with two images immediately after hearing a spoken word. The phonological code for one of the images rhymed with the spoken word while the other was phonologically unrelated to the spoken word. The Featurally-Underspecified Lexicon suggests that while non-coronal phonemes can activate other non-coronal as well as coronal phonemes, coronal phonemes themselves can only activate other coronal phonemes due to their underspecification in the lexicon. If these assumptions are correct, then it would be expected that participants may be faster looking at the rhyme competitor when the spoken word starts with a non-coronal phoneme and the rhyme object starts with a coronal phoneme as opposed to reverse trials.

Experiment 8 tested the hypothesis that the first phoneme of phonologically unrelated distractors may modulate the strength of the onset effect in adults. For this purpose, participants were presented with two images immediately after hearing a spoken pseudoword. The phonological code for one of the images started with the same phoneme as the spoken word whereas the other varied in its phonological similarity to the onset of the spoken word. It was predicted that looking proportions towards the onset competitor should be higher under conditions in which the first phoneme of the unrelated distractor was very different from the first phoneme of the spoken word as compared to trials where the first phoneme of the unrelated distractor was very similar to the first phoneme of the spoken word.

The **Discussion** chapter summarises the key findings of the previ-

ous experimental chapters and relates these back to continuous and incremental theories of spoken-word recognition in both infants and adults. Strengths and limitations of the design, methods and analyses used for this thesis are critically evaluated. The chapter further discusses how implicit naming and the pre-naming phase may modulate observers' processing strategies. Furthermore, the impact of different types of phonological competitors such as onset and rhyme competitors, the role of sub-phonemic features and the importance of unrelated distractors is discussed. Finally, it is examined whether continuous processing models such as TRACE (McClelland & Elman, 1986) may need to be extended in order to include assumptions made by the Featurally-Underspecified Lexicon (Lahiri & Reetz, 2010).

Chapter 2

Experiment 1: Onset vs. Rhyme

2.1 Introduction

Experiment 1 was a first attempt to replicate the *onset* and *rhyme* effects found for adults in the classic study by Allopenna et al. (1998) and investigate whether similar effects can be observed in 2-year old infants. To our knowledge, no study has so far investigated *onset* and *rhyme* effects in toddlers using the Visual World Paradigm. Previous studies have mainly employed priming methods (Mani & Plunkett, 2010, 2011; Mani & Huettig, 2012) or inter-modal preferential looking paradigms (Swingley et al., 1999) to investigate phonological effects in 2-year olds.

In the original adult experiment by Allopenna et al. (1998), participants were presented with four objects on a computer screen and were

asked to pick up one of the objects using a computer mouse. In this target present design, the named object was always among the objects presented on the screen together with one *onset* competitor, one *rhyme* competitor and one *unrelated* distractor.

For the present experiment, a target **absent** design was employed. A preliminary experiment in our lab indicated that using a target present design in 24- and 30–month-old infants leads to the majority of participants' attention to be drawn to the target object reducing the possibility for phonological competitors to further modulate infants' attention to the objects (Chow et al., 2017). Furthermore, in the present experiment, infants were not asked to pick up any of the objects but simply to look at them, similarly to the adult design employed by Huettig & McQueen (2007). Target present filler trials were presented in between experimental trials in order to demonstrate that infants are able to pick out the target object among four images and in order to prevent infants from getting frustrated with the lack of target images.

The aim of this experiment was to investigate whether infants, similarly to adults in Allopenna et al. (1998), employ a continuous processing strategy of spoken-words or whether they make use of incremental processing strategies as suggested by Swingley et al. (1999). For this purpose, the time course of looking proportions to the four images was analysed. If infants employ adult-like continuous processing strategies, a time course of looking proportion similar to the one found in Allopenna et al. (1998) would be expected with an early and high in-

crease in looking proportions towards the *onset* competitor and a later and smaller increase in looking proportions to the *rhyme* competitor. However, following Swingley et al. (1999)'s conclusion that infants employ incremental strategies of spoken-word processing, increased looking proportions towards the *onset* competitor should be expected while there should be no preference for the *rhyme* competitor.

Finally, the same experiment was conducted with adults as a proof of concept that the present experimental design is suitable to demonstrate phonological competition during spoken-word recognition in adults. Since previous evidence suggests that adults' looking behaviour towards *rhyme* competitors may be modulated by the degree of phonological similarity between the first phoneme of the spoken word and the *rhyme* competitor (Connine et al., 1993), such similarity scores were also taken in consideration for the analysis of adult data.

2.2 Methods

2.2.1 Participants

Thirty-one adults took part in this study. Adult participants were native English speakers aged between 18.52 and 22.62 years ($M = 19.47$, $SD = 0.81$) who were recruited from the University of Oxford. There were 20 females and 11 males. All adult participants reported normal or corrected-to-normal vision and no history of language or hearing impairments.

Forty-nine infants aged between 24 and 30 months ($M = 27.14$, $SD = 2.22$, Female: 24, Male: 25) recruited from monolingual British households were also included in the analysis of this study. Infant participant were recruited from the Oxford BabyLab participant database. The database contains contact information from families around Oxfordshire who have volunteered to be contacted for potential studies for their children. Most of the contact information were gathered through Oxford BabyLab's recruitment officer who visits the maternity ward of the JR hospital on a regular basis and asks new parents if they are happy to join the database. Additional data entries come from a contact form which parents can fill out on the website of the Oxford BabyLab. Only families with monolingual infants were contacted which were not born more than six weeks pre-term. Seven additional infants were excluded from analysis due to being fussy (3), problems with the calibration of the eye-tracker (1), having a non-British-speaking parent (2) and one parent repeating the spoken words to their child during the experiment (1).

2.2.2 Design

In order to investigate the time course of looking proportions to images that are phonologically related or unrelated to target auditory words, eye movements were recorded in a visual world paradigm displaying four pictures. The experiment consisted of two types of trials: **target absent** trials which served as experimental trials and **target present**

trials which were used as filler trials. On **target absent** trials, the object that participants were instructed to look at was not present among the four pictures displayed on the screen. However, two phonologically related objects were shown: one *onset* competitor which had a phonologically related onset to the auditory target word (i.e. *house* - *hand*) and one *rhyme* competitor which rhymed with the target word (i.e. *house* - *mouse*). The two remaining distractors were neither phonologically, semantically nor visually related to the target word. On **target present** trials, the object that participants were instructed to look at was among the four pictures displayed; together with three distractor objects that were phonologically, visually and semantically unrelated to the target object. **Target present** trials served to prevent participants from getting frustrated by the absence of target objects and from detecting the relationship between target words and phonological competitors. In total, there were 16 experimental trials and 25 filler trials. Eye movements were recorded using a Tobii TX300 automated eye-tracker. Looking proportions per time bin to *onset* competitors, *rhyme* competitors and *unrelated* distractors served as the dependent variable.

2.2.3 Stimuli

A list of stimuli was created by extracting all monosyllabic words from the Oxford Communicative Development Inventories (CDI, Hamilton et al. (2000)). Only words that were imageable were further consid-

ered. Within the remaining imageable, monosyllabic words which are normally understood by infants at the age of 2 years, rhyme-pairs were defined. Each *rhyme* competitor object also appeared as an *onset* competitor and as an *unrelated* distractor (apart from "foot" which never acted as a *rhyme* and "ship" which never occurred as an *onset*). Remaining imageable, monosyllabic words were used to create **target absent** trials.

Participants were presented with one of four pseudo-randomised lists (see Appendix A.1, A.2, A.3, A.4). Each list started with 3 target present trials; and target absent trials never occurred back-to-back. Every time an object was repeated, a different image of this object was presented (i.e. there were three different images for each object). In order to avoid possible priming effects, there were always at least three trials (i.e. 14.76 seconds) in between trials that contained the same objects.

2.2.4 Procedure

On each trial, participants were first presented with an attention getter in the middle of the screen. The attention getter comprised of a rotating twirl that lasted for 1720ms and was accompanied by a sparkling sound lasting one second. A four picture display appeared immediately after the offset of the attention getter and stayed on the screen for 3200ms. The visual display was accompanied by an auditory sentence instructing participants to look at the target object (e.g. "Look at the

cat"). The onset of the target word appeared 200ms after the onset of the visual display. There was therefore a 200ms pre-naming phase and a 3000ms post-naming phase (see fig. 2.1). The pre-naming phase of 200ms was chosen despite Huettig & McQueen (2007) not finding phonological effects with 200ms pre-naming phase. However, preliminary results from an undergraduate project undertaken in our lab led to the impression that phonological effects can indeed be demonstrated with an extremely short pre-naming phase.

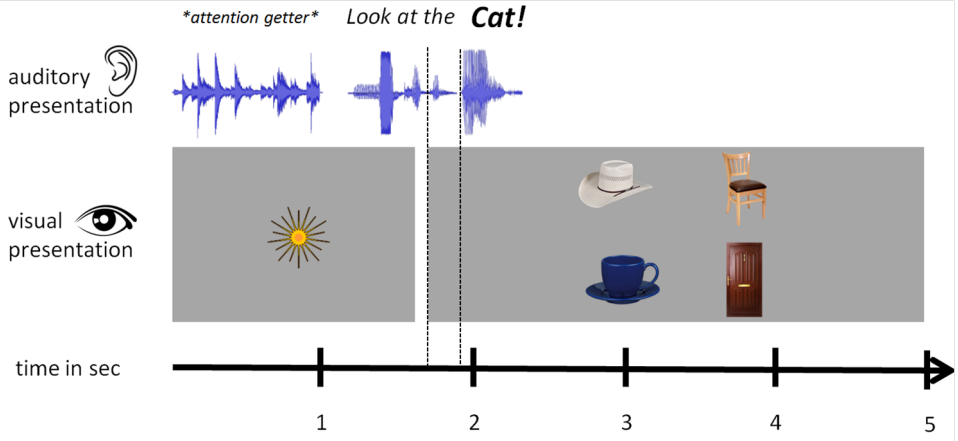


Figure 2.1: Example Trial

2.2.5 Analysis

Sixty trials were excluded from analysis (adults: 42 (3.29%), infants: 18 (1.41%)) because they contained more than 75% track loss. Track loss occurs when the eye-tracker is unable to calculate the position of the eyes, for instance due to participants moving or looking at an area outside of the screen. Furthermore, the first four trials were removed

for one adult participant due to the sound not being played correctly during these trials. Data for adults and infants were analysed separately. The minimum amount of time for a fixation to be considered as such was 100ms. For each data set, looking proportions to each of the four pictures were calculated per time bin across all participants and target absent trials. Each time bin was 100ms long and data was analysed from the onset of the visual display showing the four objects to the end of the visual presentation (3200ms total). Looking proportions were calculated in a way that any time spent looking outside of any of the four pictures was excluded from the calculation. Looking proportions for each time bin therefore always add up to 1. Pre-processing of eye-tracking data was conducted using a custom-made script in Matlab2016a. All statistical analyses were carried out using R 3.5.1 in RStudio. Transformation of eye-tracking data, track loss analysis and time bin analysis were conducted using the EyetrackingR package (Dink & Ferguson, 2015) while the glmmPQL function from the MASS package (W. N. Venables, 2002) was used for regression analyses. For all time bin and regression analyses, looking proportions for the two unrelated distractors were aggregated and compared to looking proportions for *onset* and *rhyme* competitors. For the purpose of time bin analyses, t-tests were conducted on each 100ms time bin and Holmes-Bonferroni correction was performed to correct for multiple comparisons.

For infant participants, **target present** filler trials were also analysed in order to confirm that infants performed the task as expected when

a target was present among the images presented.

Phon Scores Previous studies suggest that *rhyme* effects may be modulated by the phonological similarity between the first phoneme of the *rhyme* competitor and the spoken word (Connine et al., 1993). In order to be able to take such sub-phonemic details into account, it was determined for each experimental trial how phonologically similar the onset of the *rhyme* competitor was to the onset of the spoken word. This was done by assessing how many place, voice or manner changes separated these onsets. Low *Phon Scores* indicate that the onset of the *rhyme* was phonologically similar to the onset of the spoken word (e.g. *p* - *b*) while high *Phon Scores* indicate that the onset of the *rhyme* competitor was phonologically dissimilar to the spoken word (e.g. *m* - *h*). For an overview of the individual scores, see A.5.

2.3 Results

2.3.1 Adults

Figure 2.2 displays the time course of looking proportions to the four pictures averaged across all adult participants and trials.

Growth Curve Analysis

The overall time course of looking proportions between 200-2200ms after the onset of the visual display was modelled with fourth-order

orthogonal polynomials and fixed effect of *competitor type* on all time terms. Unrelated distractors were combined and treated as the baseline and parameters were estimated for *onset* and *rhyme* competitors. The model also included random effects of participants on all time terms and random effects of auditory stimulus nested under participant random effects on all time terms.

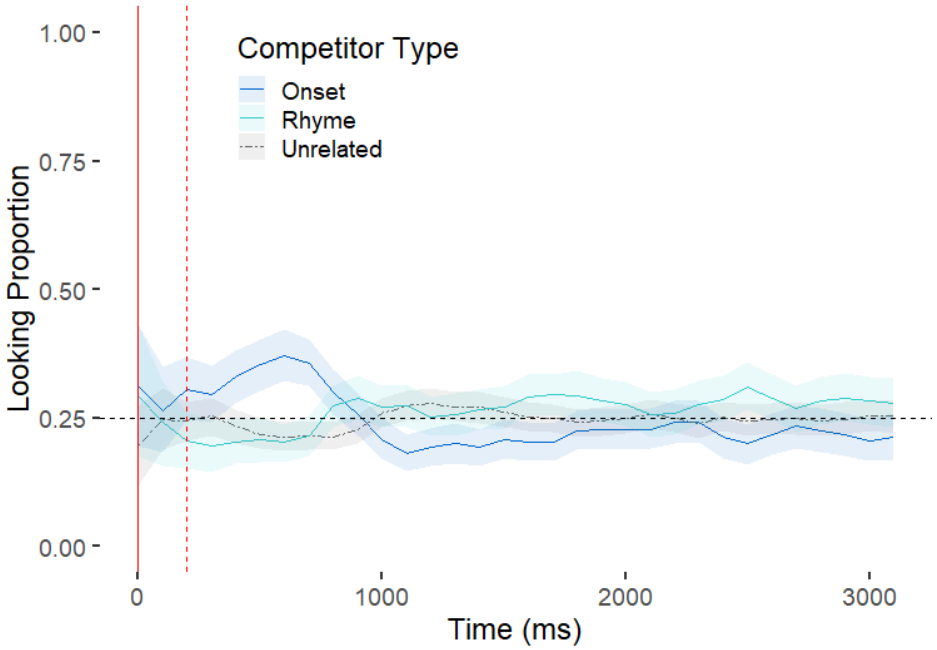


Figure 2.2: Overall Looking Proportions for adults. The solid red line marks the onset of the visual display, the dotted red line marks the onset of the auditory word and the dotted horizontal line represents looking proportions at chance level of 0.25.

Figure 2.3 shows the model between 200 and 2200ms after onset of the visual display. The figure suggests early increased looking proportions to the *onset* competitor starting at target word onset and lasting approximately 800ms. The results of the statistical model are

summarised in Table 2.1. There was a significant intercept for *onset* competitors showing that looking proportions to *onset* competitors were generally higher than for *unrelated* distractors. The significant linear, quadratic, cubic and quartic terms for the *onset* competitor suggest that the trajectory of looking times differed between *onset* competitors and *rhyme* as well as *unrelated* distractors. None of the terms were significant for the *rhyme* competitor, however, there was a trend towards a significant intercept as well as a trend towards significant quadratic and quartic terms suggesting a trend for a difference in amplitude as well as trajectory of looking proportions towards *rhyme* competitors and *unrelated* distractors.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Onset	Intercept	-1.72(0.42)	-4.08	<.001***
	Linear	-13.68(3.23)	-4.24	<.001***
	Quadratic	-12.72(3.13)	-4.06	<.001***
	Cubic	-7.54(1.783)	-4.23	<.001***
	Quartic	-6.15(1.00)	-6.16	<.001***
Rhyme	Intercept	-0.72(0.42)	-1.71	0.087
	Linear	-4.59(3.19)	-1.44	0.151
	Quadratic	-5.85(3.12)	-1.88	0.061
	Cubic	-2.46(1.76)	-1.40	0.161
	Quartic	-1.72(1.01)	-1.71	0.088
		***p<.001, **p<.01, *p<.05		

Table 2.1: Results of first adult model with fixed effects of competitor type and random effects of participants and sound stimulus.

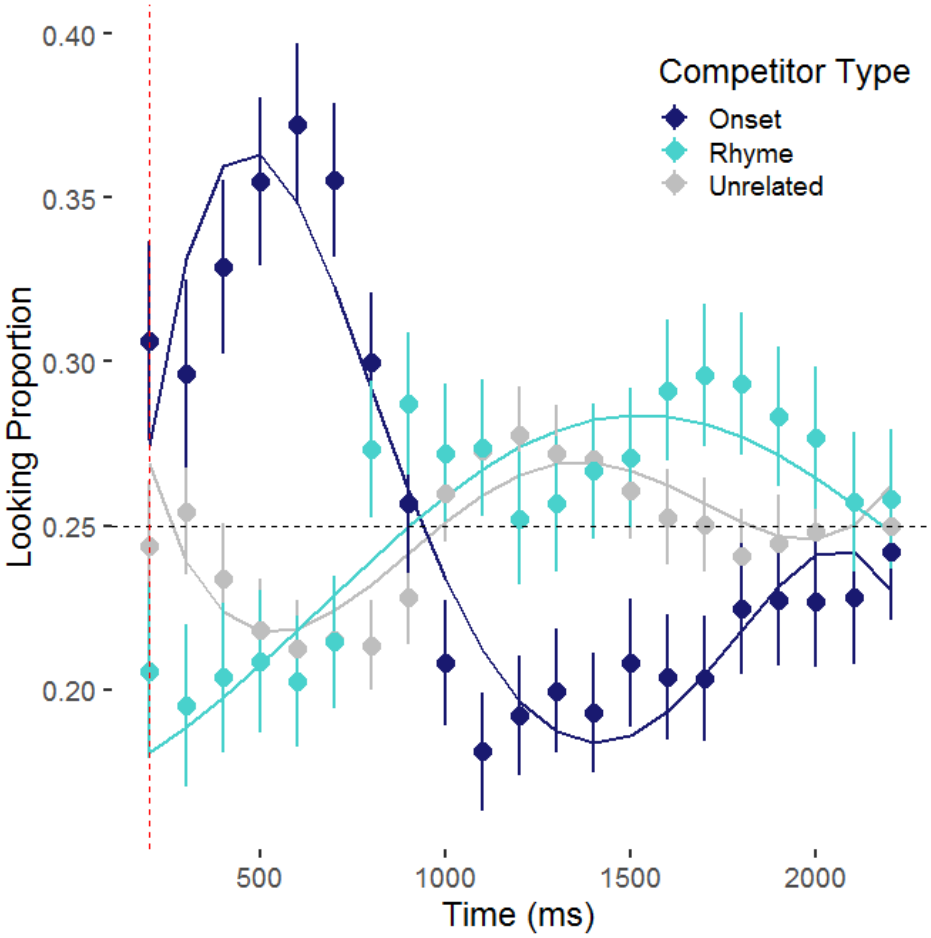


Figure 2.3: Growth curve analysis for adult data. Points represent data and lines display the model.

Growth Curve Analysis: Onset of the *Rhyme*

A second model was identical to the first model but with an added fixed effect of *Phon Scores* on all time terms. *Phon Scores* represented the phonological similarity between the onset of the *rhyme* and the onset of the spoken word for each trial. The results of the second model are summarised in Table 2.2.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Onset	Intercept	0.96(0.97)	0.99	0.323
	Linear	12.34(7.38)	1.67	0.094
	Quadratic	8.83(7.20)	1.23	0.220
	Cubic	6.38(4.08)	1.57	0.117
	Quartic	2.22(2.32)	0.96	0.338
Rhyme	Intercept	0.52(0.95)	0.55	0.582
	Linear	5.99(7.24)	0.83	0.408
	Quadratic	4.75(7.05)	0.67	0.501
	Cubic	3.22(3.98)	0.81	0.418
	Quartic	1.95(2.27)	0.86	0.390
Phon Scores	Intercept	0.17(0.08)	2.13	0.034*
	Linear	1.62(0.62)	2.61	0.009**
	Quadratic	1.42(0.60)	2.36	0.018*
	Cubic	0.86(0.34)	2.53	0.011*
	Quartic	0.53(0.19)	2.77	0.006**
Onset * Phon Scores	Intercept	-0.45(0.14)	-3.11	0.002**
	Linear	-4.32(1.10)	-3.94	<.001***
	Quadratic	-3.60(1.07)	-3.36	<.001***
	Cubic	-2.31(0.61)	-3.82	<.001***
	Quartic	-1.39(0.34)	-4.07	<.001***
Rhyme * Phon Scores	Intercept	-0.21(0.14)	-1.48	0.138
	Linear	-1.79(1.08)	-1.66	0.097
	Quadratic	-1.80(1.05)	-1.70	0.088
	Cubic	-0.96(0.59)	-1.62	0.105
	Quartic	-0.63(0.34)	-1.84	0.066
		***p<.001, **p<.01, *p<.05		

Table 2.2: Results of second adult model with fixed effects of competitor type and *Phon Scores* and random effects of participants and auditory stimulus.

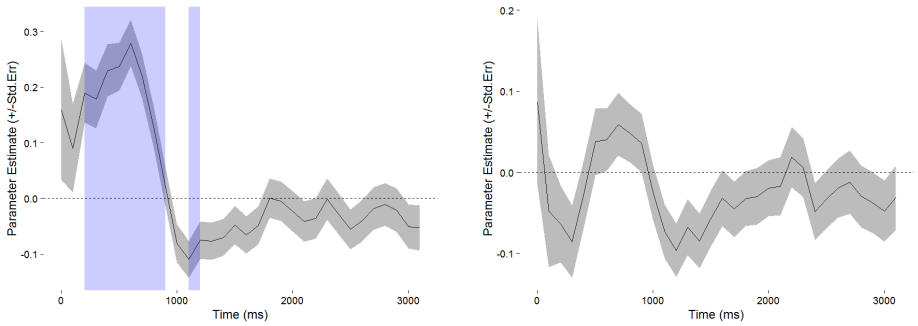
There was a significant intercept for *Phon Scores* indicating that the more phonologically dissimilar the onset of the *rhyme* was from the onset of the spoken word on a trial, the higher were looking proportions to *onset* and *rhyme* competitors in general. The significant linear, quadratic, cubic and quartic terms for *Phon Scores* further suggest that *Phon Scores* influenced the trajectory of looking proportions over time in general. The significant interaction between *onset* and *Phon Scores* on the intercept indicates that looking proportions to the *onset* competitor were influenced by *Phon Scores*. The significant linear, quadratic, cubic and quartic terms for this interaction further indicate that the trajectory of looking proportions to *onset* competitors was modulated by *Phon Scores* - the rate of change in looking proportions increased with dissimilarity between the onset of the *rhyme* and the onset of the target word. There was no significant interaction between *rhyme* competitor and *Phon Scores*, however, there was a trend towards significant interactions on the linear, quadratic and quartic terms suggesting that the trajectory of looking proportions towards the *rhyme* competitor may have been slightly modulated by *Phone Scores*.

Median Split *Phon Scores*

Following the discovery that *Phon Scores* mediate phonological effects, a median split was performed for the adult data. The median split divided adult data into 8 trials containing large phonological dissimilarities between the onset of the *rhyme* and the onset of the target word

(e.g. *moon* - *spoon*); and 8 trials with small dissimilarities between the onset of the *rhyme* and the onset of the target word (e.g. *pear* - *bear*). Figure 2.5 displays looking proportions for high and low *Phon Scores*, respectively.

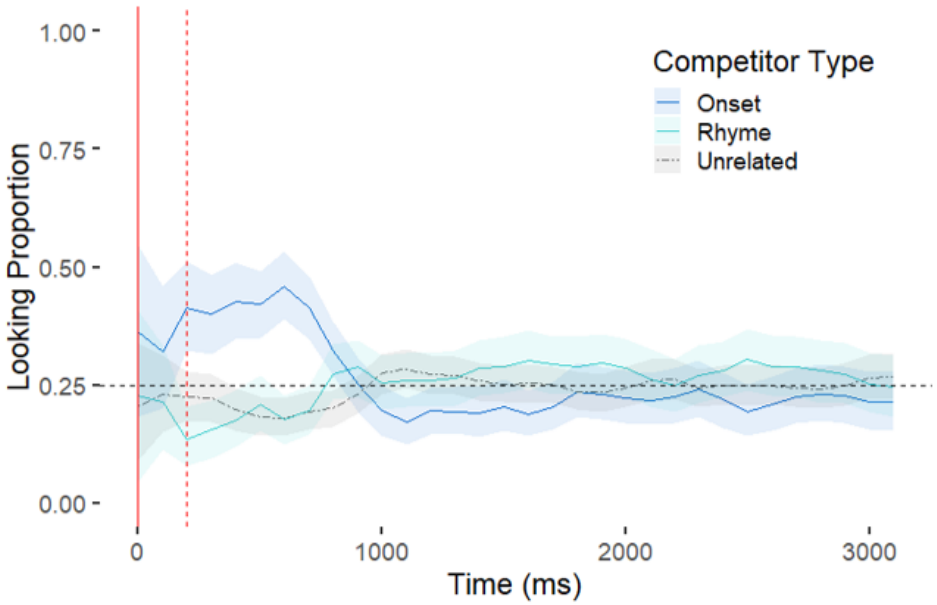
Timebin analysis (fig. 2.4) revealed that looking proportions were significantly higher towards *onset* competitors than *unrelated* distractors between 200-900ms after onset of the visual display; and significantly higher towards *unrelated* distractors than *onset* competitors between 1100-1200ms after onset of the visual display when the onset of the *rhyme* was very dissimilar to the onset of the target word (fig. 2.4a). No *onset* effect was present when the onset of the *rhyme* was very similar to the onset of the target word (fig. 2.4b).



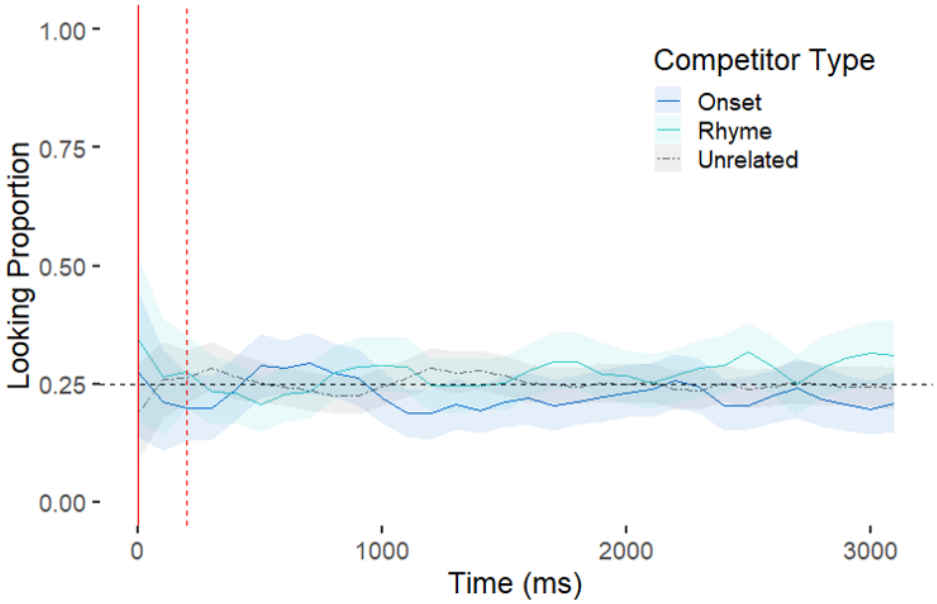
(a) *High Phon Scores*: Onset of rhyme is **dissimilar** from onset of target word

(b) *Low Phon Scores:* Onset of rhyme is **similar** to onset of target word

Figure 2.4: Timebin Analysis of **Onset** effect for high and low Phon Scores



a) *High Phon Scores*: Onset of rhyme is **dissimilar** from onset of target word.



b) *Low Phon Scores:* Onset of rhyme is **similar** to onset of target word.

Figure 2.5: Comparing trials on which the onset of the rhyme was phonologically dissimilar vs. similar to the onset of target word

Growth Curve Analysis: Onset of the *Unrelated* Distractor

Finally, a third model was identical to the second model but with an added fixed effect of *Distractor Phon Scores* on all time terms. *Distractor Phon Scores* represented the phonological similarity between the onset of the *unrelated* distractor and the onset of the spoken word for each trial. The results of the third model are summarised in Table 2.3.

There was a significant intercept for *Distractor Phon Scores* indicating that the more phonologically dissimilar the onset of the *unrelated* distractor was from the onset of the spoken word on a trial, the higher were looking proportions to *onset* and *rhyme* competitors in general. The significant linear, quadratic, cubic and quartic terms for *Distractor Phon Scores* further suggest that *Distractor Phon Scores* influenced the trajectory of looking proportions over time in general. The significant interaction between *onset* and *Distractor Phon Scores* on the intercept indicates that looking proportions to the *onset* competitor were influenced by *Distractor Phon Scores*. The significant linear, quadratic, cubic and quartic terms for this interaction further indicate that the trajectory of looking proportions to *onset* competitors was modulated by *Distractor Phon Scores* - the rate of change in looking proportions increased with dissimilarity between the onset of the *unrelated* distractor and the onset of the target word. There was no significant interaction between *rhyme* competitor and *Distractor Phon Scores* on the intercept. However, there were significant interactions on the linear, quadratic and quartic terms suggesting that the trajectory of looking

proportions towards the *rhyme* competitor was also modulated by *Distractor Phone Scores*.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Onset	Intercept	0.31(0.95)	0.33	0.743
	Linear	5.54(7.23)	0.77	0.444
	Quadratic	3.83(7.02)	0.55	0.585
	Cubic	2.23(4.00)	0.56	0.577
	Quartic	1.31(2.24)	0.58	0.559
Rhyme	Intercept	0.83(0.93)	0.89	0.371
	Linear	9.02(7.07)	1.28	0.202
	Quadratic	4.31(6.93)	0.62	0.534
	Cubic	5.92(3.88)	1.52	0.127
	Quartic	2.95(2.23)	1.32	0.187
Distractor Phon Scores	Intercept	0.18(0.08)	2.13	0.033*
	Linear	1.60(0.63)	2.53	0.012*
	Quadratic	1.32(0.61)	2.16	0.031*
	Cubic	0.88(0.35)	2.53	0.011*
	Quartic	0.59(0.20)	3.02	0.003**
Onset * Distr. Phon Scores	Intercept	-0.35(0.15)	-2.41	0.016*
	Linear	-3.34(1.11)	-3.00	0.003**
	Quadratic	-2.86(1.08)	-2.65	0.008**
	Cubic	-1.70(0.62)	-2.76	0.006**
	Quartic	-1.29(0.34)	-3.73	<.001***
Rhyme * Distr. Phon Scores	Intercept	-0.28(0.14)	-1.92	0.055
	Linear	-2.44(1.10)	-2.22	0.026*
	Quadratic	-1.83(1.07)	-1.70	0.089*
	Cubic	-1.50(0.60)	-2.48	0.013*
	Quartic	-0.83(0.35)	-2.40	0.016*
		***p<.001, **p<.01, *p<.05		

Table 2.3: Results of third adult model with fixed effects of competitor type and *Distractor Phon Scores* and random effects of participants and auditory stimulus.

2.3.2 Infants

Figure 2.6 displays the time course of looking proportions to the four pictures averaged across all infant participants and trials.

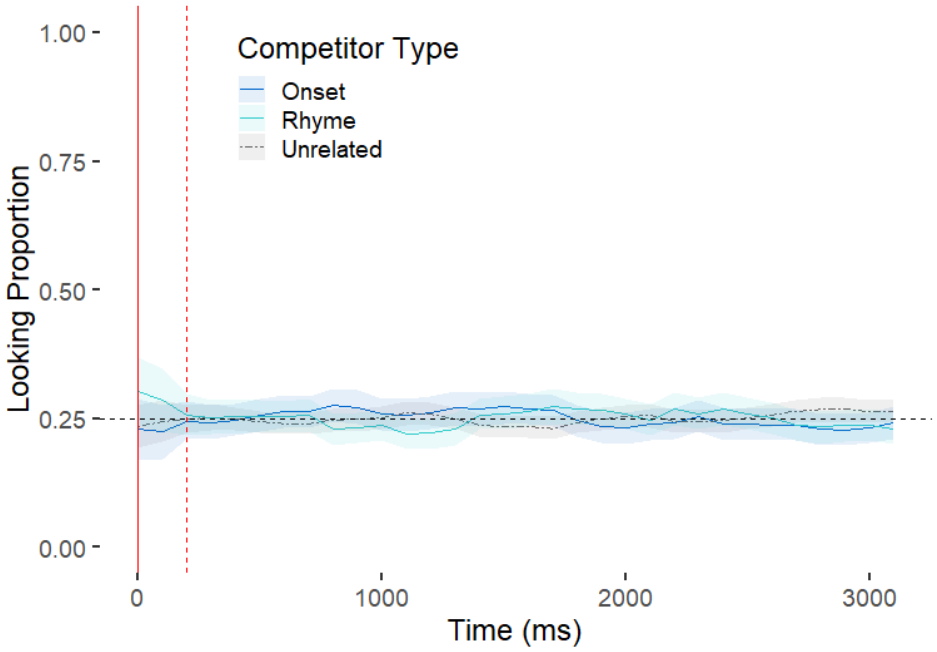


Figure 2.6: Overall Looking Proportions Infants. The solid red line marks the onset of the visual display, the dotted red line marks the onset of the auditory word and the dotted horizontal line represents looking proportions at chance level of 0.25.

Growth Curve Analysis

A different time window was used to model the infant data than for the adult data. This was done because infants are expected to take longer than adults until they make a first target fixation in a visual world paradigm. Typically, 2-year-olds start fixating target objects approximately 680ms after onset of the spoken word (Fernald et al., 1998). The

overall time course of looking proportions between 600-3200ms after the onset of the visual display was modelled with third-order orthogonal polynomials and fixed effects of *competitor type* on all time terms. Unrelated distractors were treated as the baseline and parameters were estimated for *onset* and *rhyme* competitors. The model also included random effects of participants on all time terms and random effects of auditory stimulus nested under participant random effects on all time terms.

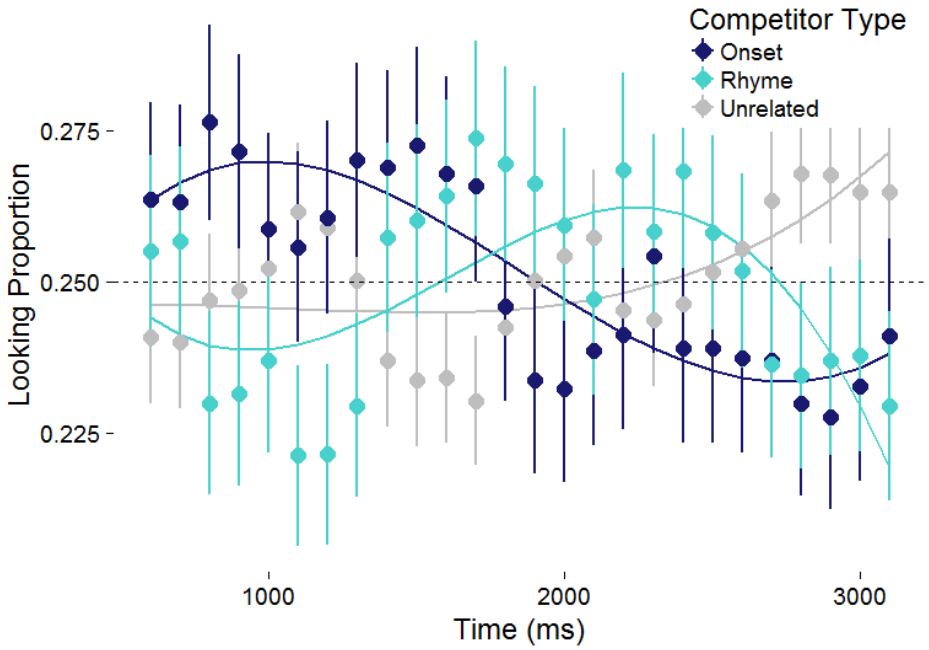


Figure 2.7: Growth curve analysis for infant data. Points represent data and lines display the model.

Figure 2.7 shows the model between 600 and 3200ms after onset of the visual display. The figure suggests no preference for any of the phonologically related competitors over unrelated competitors.

The results of the statistical model for infants are summarised in Table 2.4. There were no significant effects on the intercept, linear or quadratic terms for either type of phonological competitor. There was a significant effect on the cubic term for *rhyme* competitors but not for *onset* competitors. Adding *Phon Scores* to the model did not lead to significantly higher model fit.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Onset	Intercept	0.00(0.04)	0.08	0.937
	Linear	-0.34(0.315)	-1.09	0.278
	Quadratic	-0.41(0.29)	-1.40	0.163
	Cubic	0.18(0.21)	0.84	0.399
Rhyme	Intercept	0.01(0.04)	0.29	0.771
	Linear	-0.32(0.32)	-0.10	0.318
	Quadratic	-0.06(0.30)	-0.19	0.848
	Cubic	-0.46(0.22)	-2.15	0.032*
		***p<.001, **p<.01, *p<.05		

Table 2.4: Results of infant model with fixed effects of competitor type.

2.3.3 Target Present Trials

Target present filler trials were analysed for infant data in order to check whether the lack of any phonological effects may stem from infants not conducting the task as expected. For this purpose, the overall time course of looking proportions between 0-3000ms after the onset of the visual display was modelled with third-order orthogonal polynomials and fixed effect of *object type* on all time terms. The

distractor objects from **target present** trials were concatenated and treated as the baseline. Parameters were estimated for the *target* object. The model also included random effects of participants and stimulus type on all time terms. Figure 2.8 shows the model between 0 and 3000ms after onset of the visual display. The figure suggests increased looking proportions towards *target* objects starting approximately one second after onset of the visual display.

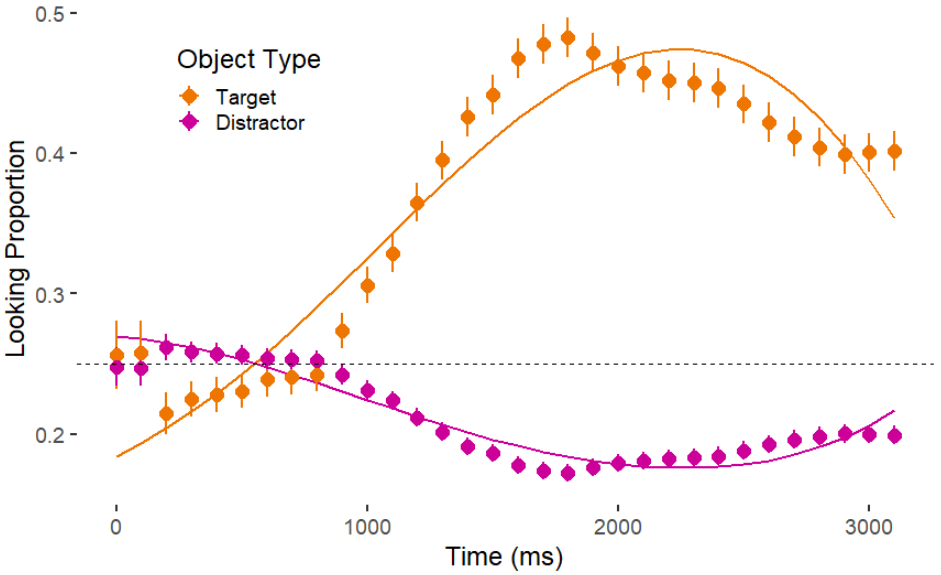


Figure 2.8: Growth curve analysis for target competitors versus unrelated distractors. Points represent data and lines display the model.

The results of the statistical model are summarised in Table 2.5. There was a significant intercept suggesting that looking proportions towards the *target* were generally higher than for the *unrelated* distractor. Furthermore the linear, quadratic and cubic terms were significant for the *target* object suggesting that looking proportions towards the

target followed a different pattern than towards *distractor* objects.

Fixed Effects	Model Terms	Est. (SE)	*t*	*p*
Target	Intercept	0.74(0.01)	52.32	<.001***
	Linear	2.95(0.09)	32.60	<.001***
	Quadratic	-1.79(0.09)	-19.70	<.001***
	Cubic	-0.75(0.09)	-8.63	<.001***
			***p<.001, **p<.01, *p<.05	

Table 2.5: Results of the second infant model with fixed effects of object type.

2.4 Discussion

Experiment 1 partially replicated findings by Allopenna et al. (1998) displaying early increased looking proportions to *onset* competitors in adults. However, despite some trends, no significant increased looking proportions to *rhyme* competitors could be found in adults. Furthermore, no preference for either type of phonological competitors was found in infants using the present setup.

2.4.1 Theories of Spoken-Word Recognition

Analysis of target present filler trials showed that when a target was present among the visual display, infants looked at the target object as expected, thus, confirming that infants were generally engaging in the task as expected. However, unlike expected, infants did not prefer any

type of phonological competitor over the unrelated distractors. This seems to suggest that infants' attention was not driven by phonological competition during the process of spoken-word recognition. Such findings could imply that when processing spoken language, 2-year-olds' attention is more directed by factors such as semantic or visual similarity. Such strategies might be beneficial at this age group since excluding possible lexical candidates simply based on their phonology may hinder infants in learning new words which are not part of their lexicon yet (Walley, 1993). However, it is also possible that the present setup was not sensitive enough in order to pick up effects of phonological competition in infants. Due to the small number of trials used, the current study may not have had enough statistical power in order to be able to detect relatively small effects of phonological competition. Experiment 3 will therefore use a much larger set of trials.

The adult results suggest that adults' attention was mainly driven by the first phoneme of a spoken word. Despite the *rhyme* having a larger phonological overlap with the spoken word than the *onset* competitor, no significant *rhyme* effects could be observed. Such findings would support incremental processing strategies of spoken words such as the Cohort model (Marslen-Wilson, 1987) which suggests that upon hearing the initial sound of a word, possible word candidates starting with the same phoneme become activated. According to this theory, candidate words are gradually excluded as the spoken word unfolds. The present results would suggest that any *rhyme* competitors were excluded as

possible candidates as soon as the first phoneme of the spoken word was revealed due to the mismatch in the initial phoneme. However, an alternative explanation could be that by presenting the *rhyme* competitor together with the *onset* competitor, the *onset* competitor may have been chosen as a possible candidate very early on due to its match with the initial phoneme of the spoken word and thereby could have inhibited any attention from being directed to the *rhyme* competitor.

2.4.2 Competition between *Onset* & *Rhyme*

Presenting *onset* and *rhyme* competitors simultaneously might have created a competition between these two phonological competitors which meant that infants did not prefer any type of phonological competitor over the unrelated distractors. Furthermore, having *onset* and *rhyme* competitors directly compete with each other in this visual world paradigm might be the reason why adults did not show significant increased looking proportions for the *rhyme* competitor. The considerably stronger *onset* effects may simply have overshadowed the weaker *rhyme* effect. To date, only a limited number of studies have reported increased looking proportions to *rhyme* competitors in adults using a visual world paradigm. The most cited is Allopenna et al. (1998). It is important to note that for the purposes of their analysis, the authors combined trials on which *rhyme* or *onset* competitors were presented in isolation together with unrelated distractors and trials in which *rhyme* and *onset* competitors were directly put into competition with each

other. It is possible that clear *rhyme* effects can only be observed when the *rhyme* is presented without an *onset* competitor being present. If this is the case, then the increased times spent looking at the *rhyme* distractor observed in Allopenna et al. (1998) might simply stem from trials in which the *rhyme* was presented in absence of an *onset* distractor. To examine this idea, Experiment 3 will investigate looking proportions when *onset* and *rhyme* competitors do not occur on the screen simultaneously.

However, a further possible explanation for the differing results between the study by Allopenna et al. (1998) and the present adult results could be the large amount of trial repetitions in Allopenna et al. (1998). It is possible that the present lack of a *rhyme* effect may be due to the much smaller number of trials used for the present experiment. Experiment 3 will therefore make use of a larger amount of trials than Experiment 1.

2.4.3 The *Rhyme* Effect

There is still debate on whether upon hearing a word, lexical candidates that do not share an onset with the target word may be activated (Zwitserlood, 1996). Such activation might only occur when word boundaries are ambiguous (Tabossi et al., 1995). There is some evidence that non-word primes can activate *rhyme* (Connine et al., 1993). However, when using real words, *rhyme* activation only seems to occur when the onset of the *rhyme* is very similar to the target on-

set. Brouwer & Bradlow (2015) used a similar task to Allopenna et al. (1998) and compared looking behaviour in a quiet condition with a condition in which background noise was added to the speech input. They only found a *rhyme* preference over the distractor in the noisy condition. This is in accordance with findings by McQueen & Huettig (2012) who showed increased *rhyme* competition under ambiguous conditions. Taken together, these findings suggest that under conditions in which information is not very reliable, listeners become more error tolerant and are less likely to immediately eliminate words as possible lexical candidates. However, under unambiguous conditions, the findings are much less clear.

Examining infant studies, there is as of yet no study that found *rhyme* effects in infants younger than 3 years old. Using a 2-picture visual world paradigm with infants, Swingley et al. (1999) showed that 2-year-old infants were slower to look at a target object when it was presented simultaneously with an object that had the same onset as the target object (e.g. doll-dog). However, infants were not slower in looking at a target object when it was presented together with a *rhyme* competitor (e.g. ball-doll). These findings led the authors to conclude that children process incoming spoken words incrementally, so that they disregard any words as possible lexical candidates that differ from the target word in their onset.

2.4.4 Word Length

It is possible that Allopenna et al. (1998) found increased looking proportion to rhyme competitors because they used bisyllabic words. The present study used monosyllabic rhymes which may have too little overall phonological overlap with the target word in order to create the necessary competition with onset competitors. A bisyllabic rhyme pair like *parrot* - *carrot* has many more phonemes in common than a monosyllabic rhyme pair such as *cat* - *hat*. Thus, in Allopenna et al. (1998), rhymes had a much larger percentage of overlap with the target word and therefore might have been able to compete with onset distractors.

2.4.5 Pre-naming Phase

Contrary to Huettig & McQueen (2007), the current results show that even with a pre-view time as short as 200ms, adults are sensitive to phonological similarities when presented with a visual world paradigm. One reason for the different findings could be due to the way objects were presented in the two studies. While Huettig & McQueen (2007) used line drawings of objects, the current study employed real images of objects. As Huettig & McQueen (2007) showed in their study, the way information is presented in a visual world paradigm influences the retrieval of phonological, semantic and visual information. It is possible that retrieving such information from line drawings takes longer than retrieval from photographs. Experiment 2 will therefore aim to replicate Experiment 1 using line drawings.

Using a very short pre-naming time of only 200ms, however, may have lead to some unexpected results in the present study. Unlike Chow et al. (2017), we did not find any effects of phonological competition for 24-30-month-old infants. It is possible that a pre-naming phase of 200ms was too short for infants to retrieve the phonological code for all four objects and make a decision on which object is most related to the target word. Similarly, a reduced pre-naming time of 200ms might have been the reason why we did not observe significant increased looking proportions to *rhyme* competitors in adults. This idea would be in line with findings by Huettig & McQueen (2007) who did not find increased looking times to phonologically related distractors when adults were given a short pre-naming phase of 200ms. Experiment 3 will investigate whether increasing the pre-naming phase leads to different results.

2.4.6 Coarticulation Effects

It should be noted that in the current study, there seem to be tendencies for increased looking proportion to the *onset* competitor in adults already just before or at the point of the onset of the spoken word. This may stem from the way our auditory stimuli were constructed: In order to make them sound natural, we recorded stimuli as entire sentences spoken by a native British speaker (e.g. "Look at the cat."). It is possible that we are observing coarticulation effects (Hardcastle & Hewlett, 2006) produced by the possibility that the way our speaker intonated the initial phrase before the target word may already have

given an indication for the onset of the named object. In order to avoid such effects of coarticulation in following experiments, auditory stimuli will be cut and spliced so that the same recording of the beginning phrase will be used for each target word.

2.4.7 Importance of Distractors

One novel finding of this study is that the phonological similarity between the onset of *rhyme* distractors and the onset of the spoken word has an impact on the looking proportions to *onset* competitors. In particular, the more similar the first phoneme of a *rhyme* competitor is to the first phoneme of a spoken word, the lower looking proportions are towards the *onset* competitor. Likewise, if the first phoneme of a *rhyme* competitor is very different from the first phoneme of a spoken word, looking proportions to the *onset* competitor will be particularly high. A similar influence could be found for the similarity between the onset of the *unrelated* distractor and the onset of the spoken word. It is therefore not the *onset* competitor alone that attracts participants' attention but rather a lack of competition from any other distractors. It seems as if all objects in a visual scene compete for attention and the objects that have a phonologically similar onset to the spoken word attract fixations. This finding supports the idea that the context in which spoken-word recognition happens is crucial. Experiment 8 will explicitly test if and how the onset of *unrelated* distractors may modulate *onset* effects.

Chapter 3

Experiment 2: Line Drawings

3.1 Introduction

Experiment 1 showed that adults are sensitive to phonological competition during spoken-word recognition using a visual world paradigm where participants saw four objects 200ms before they heard a target word. These findings are in contrast with Huettig & McQueen (2007) who used a similar setup but did not find phonological effects with a pre-naming phase as short as 200ms. They did, however, find effects similar to the ones presented in Experiment 1 when giving adults enough time to inspect the objects before they heard the target word. The authors explain the lack of phonological effects when using a very short pre-naming phase with the idea that by the time adults have retrieved the names of the objects presented in the visual display, these might already be inconsistent with the auditory input. This idea is

based on results by Levelt et al. (1991) who found that it takes adults approximately 385ms to retrieve the name for a single picture. Thus, if adults only have 200ms to retrieve the phonological code for the objects presented, they will already have heard the entire spoken word before finishing the naming of the objects ruling out any of the images as possible lexical candidates.

As mentioned earlier, one reason why Experiment 1 of this thesis might have produced different results from Huettig & McQueen (2007), could be the different way in which objects were presented to participants: While Huettig & McQueen (2007) used line drawings for their study, Experiment 1 employed photographs of objects. As Huettig & McQueen (2007) showed in their study, the way information is presented in a visual world paradigm influences the retrieval of phonological, semantic and visual information. It is possible that retrieving phonological information from line drawings takes longer than retrieval from photographs.

In terms of object recognition, one might argue that a line drawing is a simplified representation of an object with unnecessary details removed which may make object recognition easier. However, details provided by a photograph, such as colour and its general greater resemblance with real-life objects may facilitate object recognition (Davies et al., 1978). In an early study, Davies et al. (1978) showed that participants were significantly more accurate in recognising photographs as compared to line drawings. This even applied when very detailed line drawings were used. Ryan & Schwartz (1956) compared participants' speed of

recognition for different modes of object representations, namely cartoons, photographs and line drawings. They found that while cartoons were perceived fastest, line drawings were the most difficult to perceive. Shaded drawings, on the other hand, were perceived similarly to real photographs. Leder (1996) found that participants are less likely to detect changes in facial features if the faces were depicted as line drawings as compared to photographs while Tversky & Baratz (1985) showed that participants' performance was significantly better on a number of tasks such as name recall and face recognition when they were presented with photographs of faces rather than line drawings. In a more recent study, Rossion & Pourtois (2004) showed that adding colour and texture information to line drawings improved naming accuracy of objects as well as correct response times. These findings further suggest that object recognition is facilitated when participants are presented with objects that contain more surface details.

Finally, there seems to be a development of attention drawn by photographs and line drawings. Lewis (1969) showed that 6-month-old infants spent more time fixating on a male face when it was presented as a photograph than as a line drawing. When the same infants were presented with these stimuli again at the age of 13 months, they spent more time fixating on the line drawings.

Taken together, the above results suggest that recognition of line drawings takes significantly longer than photographs. These findings support the assumption that the difference in results between our current Ex-

periment 1 and Huettig & McQueen (2007) may stem from the different modes of representations used in the two studies.

Experiment 2 explored this hypothesis by replicating Experiment 1 and replacing all photographs of objects with their respective line drawings. If the above assumption is true, it is expected that adults will not show any increased looking proportions towards *onset* competitors when presented with line drawings and a short pre-naming phase of 200ms.

3.2 Methods

3.2.1 Participants

24 adults took part in this study. Adult participants were native English speakers aged between 18.33 and 24.41 years ($M = 19.74$, $SD = 4.14$) who were recruited from the University of Oxford. There were 18 females and 6 males. All adult participants reported normal or corrected-to-normal vision and no history of language or hearing impairments.

3.2.2 Design

The design of this study was identical to Experiment 1.

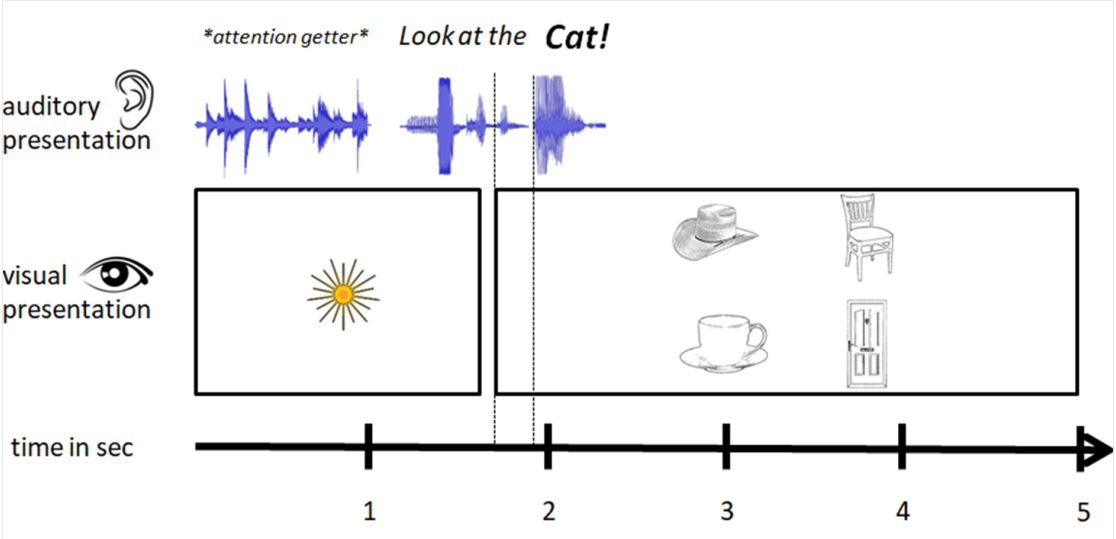


Figure 3.1: Example Trial

3.2.3 Stimuli

The stimuli for this study were identical to Experiment 1. However, images were depicted as line drawings rather than photographs. For this purpose, the original images were edited in GIMP 2.8. using desaturation, edge detection, brightness increase and contrast increase. For an overview of all the line drawings used for target absent trials, see Figure A.1. Some images for the **target present** trials had to be replaced since they would not have been recognisable as line drawings: "milk" was replaced by "dice", "stone" was replaced by "ring" and the image of a glass of juice was changed to the image of a juice box. However, since analysis will only concern **target absent** trials, these changes should have no impact on the comparability between Experiments 1 and 2.

3.2.4 Procedure

The procedure of this study was identical to Experiment 1 (fig. 3.1).

3.2.5 Analysis

Five trials (1.3%) were excluded from analysis because they contained more than 75% track loss. The remainder of data analysis was identical to Experiment 1.

3.3 Results

Figure 3.2 displays the time course of looking proportions to the four pictures averaged across all adult participants and trials.

3.3.1 Growth Curve Analysis

The overall time course of looking proportions between 200-2200ms after the onset of the visual display was modelled with fourth-order orthogonal polynomials and fixed effect of *competitor type* on all time terms. Unrelated distractors were combined and treated as the baseline and parameters were estimated for *onset* and *rhyme* competitors. The model also included random effects of participants on all time terms and random effects of auditory stimulus nested under participant random effects on all time terms.

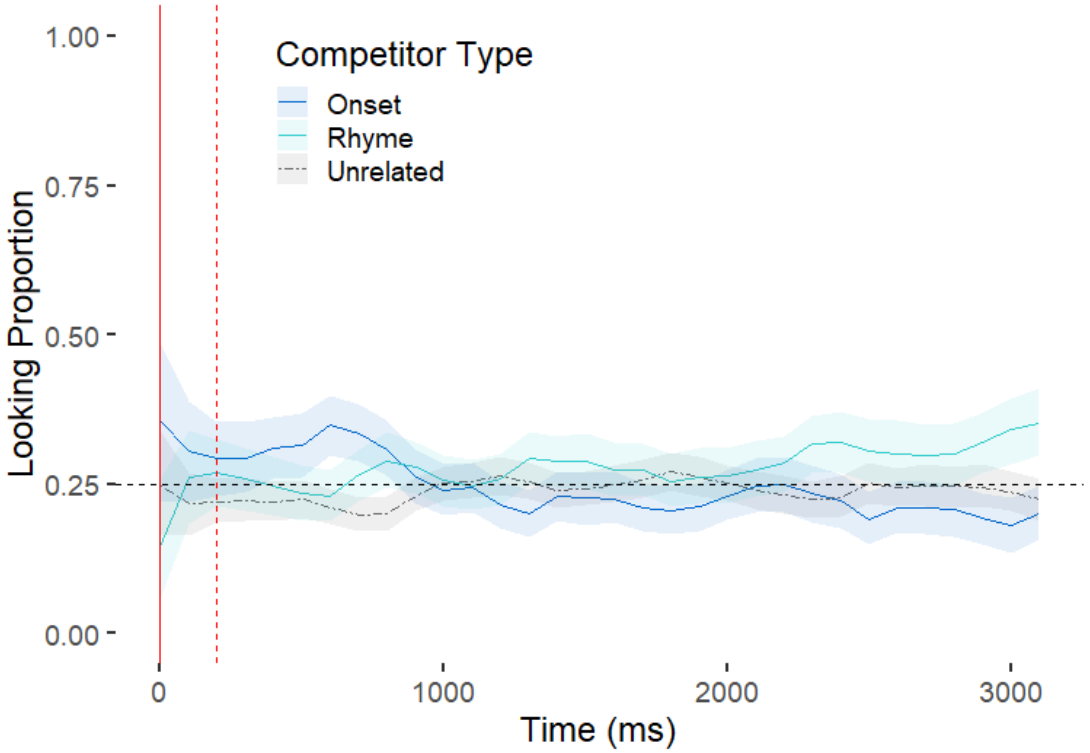


Figure 3.2: Overall Looking Proportions for Adults. The solid red line marks the onset of the visual display, the dotted red line marks the onset of the auditory word and the dotted horizontal line represents looking proportions at chance level of 0.25.

Figure 3.3 shows the model between 200 and 2200ms after onset of the visual display. The results of the statistical model are summarised in Table 3.1. There was no significant intercept for either the *onset* or the *rhyme* competitors indicating that looking proportions to both phonological competitors were not significantly higher than for *unrelated* distractors. Furthermore, none of the linear, quadratic, cubic or quartic terms were significant for either the *onset* or the *rhyme* competitors suggesting that looking proportions to all three competitor types followed a similar trajectory.

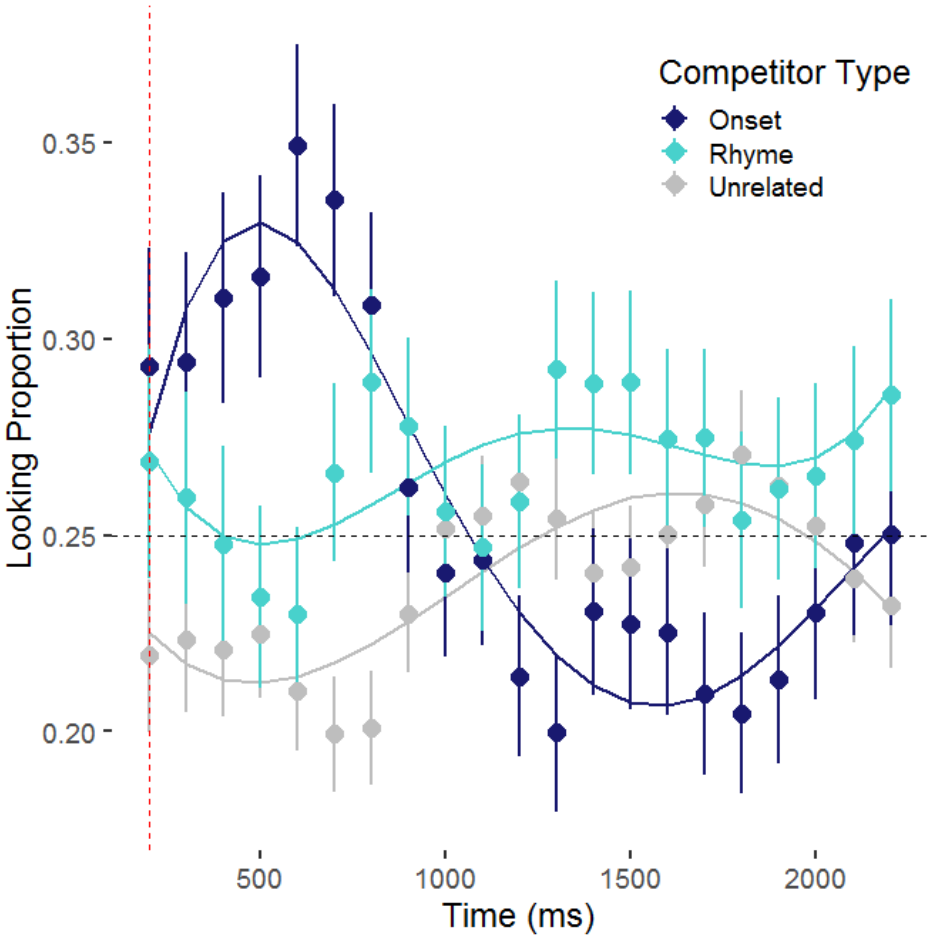


Figure 3.3: Growth curve analysis for adult data. Points represent data and lines display the model.

Fixed Effects	Model Terms	Est. (SE)	*t*	*p*
Onset	Intercept	0.07(0.46)	0.16	0.877
	Linear	-0.51(3.51)	-0.14	0.885
	Quadratic	0.05(3.38)	0.01	0.989
	Cubic	0.07(1.93)	0.03	0.973
	Quartic	-1.81(1.06)	-1.71	0.088
Rhyme	Intercept	0.07(0.45)	1.57	0.117
	Linear	4.16(3.44)	1.21	0.226
	Quadratic	4.03(3.32)	1.22	0.224
	Cubic	2.25(1.89)	1.19	0.234
	Quartic	0.84(1.05)	0.80	0.423
		***p<.001, **p<.01, *p<.05		

Table 3.1: Results of first adult model with fixed effects of competitor type

A second model was identical to the first model but with an added fixed effect of *Phon Scores* on all time terms. *Phon Scores* represented the phonological similarity between the onset of the *rhyme* and the onset of the spoken word for each trial. The results of the second model are summarised in Table 3.2.

There was a significant intercept for the *rhyme* competitor suggesting that looking proportions towards the *rhyme* competitor were generally higher than for the *unrelated* distractors. The significant linear, quadratic, cubic and quartic terms for the *rhyme* further suggest that looking proportions for *rhyme* competitors followed a different trajectory than for *unrelated* distractors. Additionally, there was a trend towards significant linear and cubic terms for the *onset* competitor sug-

gesting a slightly different trajectory of looking proportions for *onset* competitors

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Onset	Intercept	1.60(1.045)	1.53	0.126
	Linear	15.60(7.98)	1.95	0.051
	Quadratic	9.98(7.76)	1.29	0.198
	Cubic	7.72(4.39)	1.76	0.079
	Quartic	3.88(2.47)	1.578	0.117
Rhyme	Intercept	2.35(1.02)	2.31	0.021*
	Linear	18.41(7.82)	2.35	0.019*
	Quadratic	15.16(7.56)	2.01	0.045*
	Cubic	9.98(4.30)	2.32	0.020*
	Quartic	5.23(2.39)	2.19	0.029*
Phon Scores	Intercept	0.15(0.09)	1.68	0.093
	Linear	1.43(0.69)	2.06	0.039*
	Quadratic	1.03(0.67)	1.55	0.122
	Cubic	0.73(0.38)	1.92	0.055
	Quartic	0.47(0.21)	2.23	0.025*
Onset * Phon Scores	Intercept	-0.25(0.15)	-1.65	0.100
	Linear	-2.64(1.18)	-2.23	0.026*
	Quadratic	-1.65(1.14)	-1.44	0.150
	Cubic	-1.25(0.65)	-1.92	0.054
	Quartic	-0.94(0.36)	-2.60	0.009**
Rhyme * Phon Scores	Intercept	-0.27(0.15)	-1.83	0.067
	Linear	-2.38(1.15)	-2.07	0.039*
	Quadratic	-1.86(1.11)	-1.67	0.094
	Cubic	-1.29(0.63)	-2.04	0.041*
	Quartic	-0.73(0.35)	-2.08	0.038*
		***p<.001, **p<.01, *p<.05		

Table 3.2: Results of second adult model with fixed effects of competitor type and *Phon Scores*

and *unrelated* distractors. Furthermore, the significant linear and quartic terms and the trend towards a significant cubic term for *Phon Scores* suggest that the phonological similarity between the onset of the *rhyme* and the onset of the spoken word influenced the trajectory of looking proportions in general. Finally, there were significant interactions between the *rhyme* competitor and *Phon Scores* on the linear, cubic and quartic terms; as well as between the *onset* competitor and *Phon Scores* on the linear and quartic terms. These results further suggest that *Phon Scores* influenced the trajectory of looking proportions to both phonological competitors.

3.3.2 Median Split *Phon Scores*

Following the discovery that *Phon Scores* mediate phonological effects, a median split was performed for the adult data in the same way as in Experiment 1. Figure 3.4 displays looking proportions for low and high phonological dissimilarities, respectively.

Time bin analysis (fig. 3.5) revealed that looking proportions were significantly higher towards *onset* competitors than towards *unrelated* distractors between 200-900ms after onset of the visual display when the onset of the *rhyme* was very dissimilar to the onset of the target word (fig. 3.5a). No *onset* effect was present when the onset of the *rhyme* was very similar to the onset of the target word (fig. 3.5b).

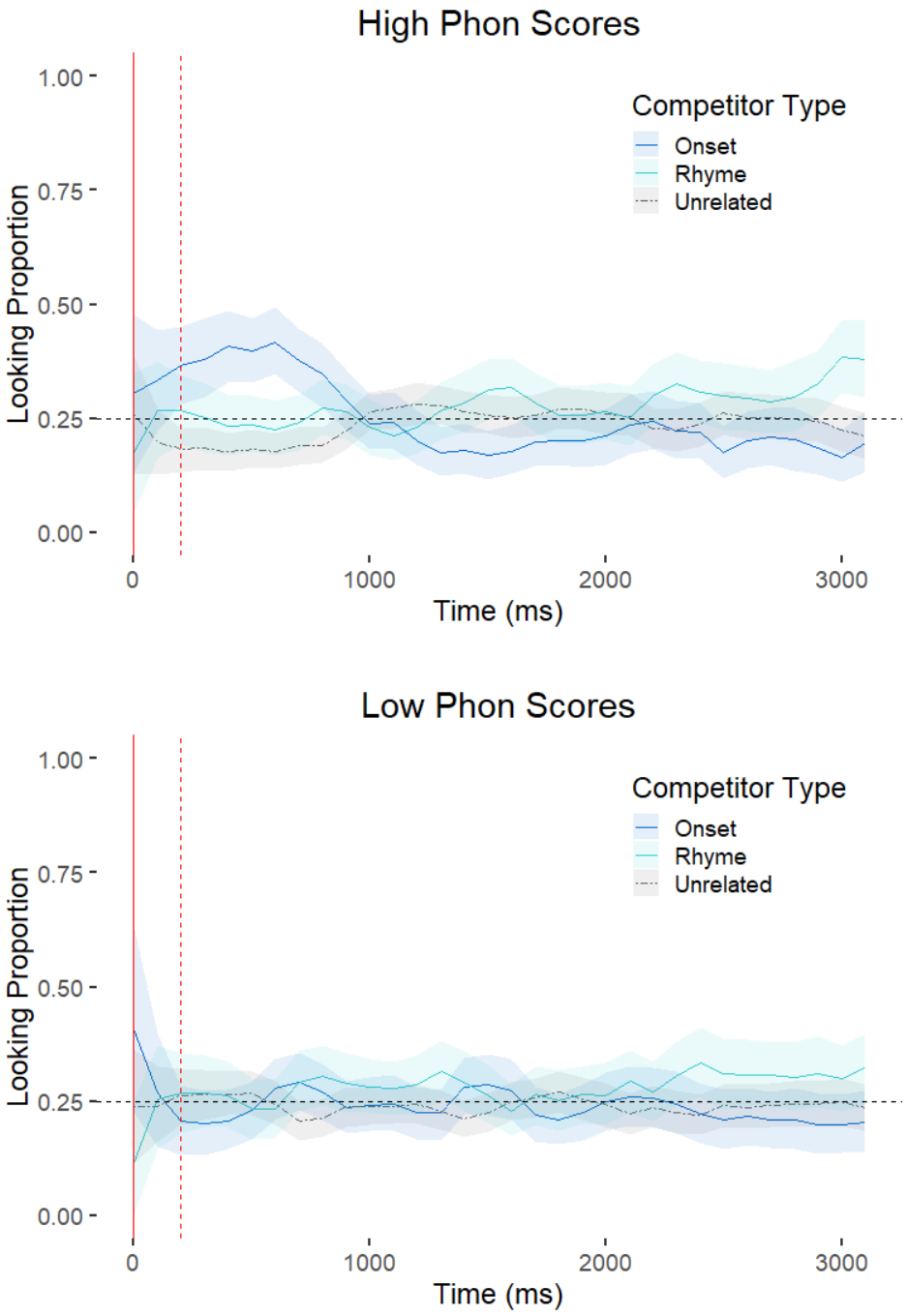
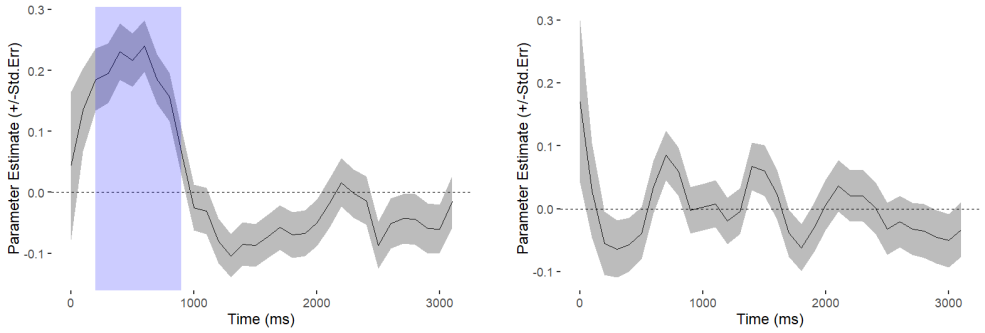


Figure 3.4: Comparing trials on which the onset of the rhyme was phonologically dissimilar vs. similar to the onset of target word



(a) *High Phon Scores*: Onset of Rhyme is **dissimilar** from onset of target word

(b) *Low Phon Scores:* Onset of Rhyme is **similar** to onset of target word

Figure 3.5: Time bin Analysis of **Onset** effect for high and low Phon Scores

3.3.3 Comparison with Experiment 1

A final model compared looking proportions to the different competitor types between Experiment 1 and Experiment 2. The overall time course of looking proportions between 200-2200ms after the onset of the visual display was modelled with fourth-order orthogonal polynomials and fixed effects of *competitor type* and *experiment* on all time terms. Unrelated distractors were combined and treated as the baseline and parameters were estimated for *onset* and *rhyme* competitors. Furthermore, Experiment 2 was treated as the baseline and parameters were estimated for Experiment 1. The model also included random effects of participants on all time terms and random effects of auditory stimulus nested under participant random effects on all time terms.

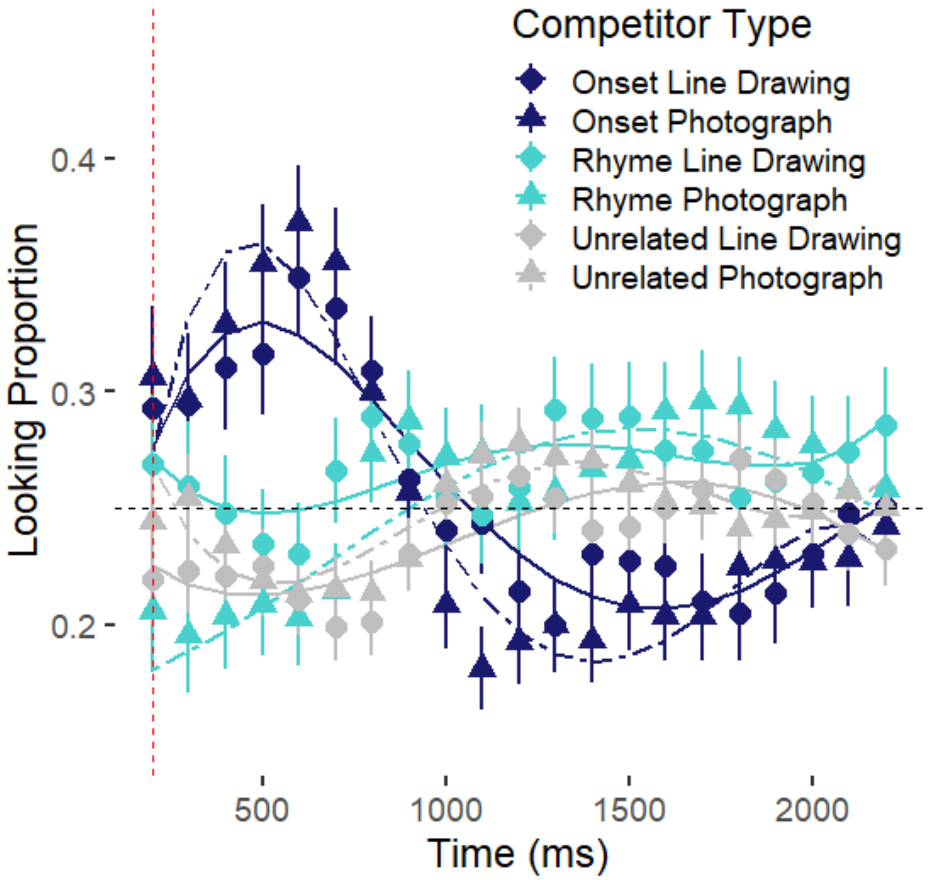


Figure 3.6: Growth curve analysis for adult data. Points represent data and lines display the model.

Figure 3.6 shows the model between 200 and 2200ms after onset of the visual display. The figure suggests that *onset* as well as *rhyme* effects were larger in the photograph experiment as compared to the line drawing experiment. The results of the statistical model are summarised in Table 3.3. There was a significant intercept for *experiment* suggesting that the magnitude of looking proportions was influenced by the type of stimuli (photographs vs. line drawings) presented in general. The significant linear, quadratic, cubic and quartic terms for *experiment*

Fixed Effects	Model Terms	Est. (SE)	*t*	*p*
Onset	Intercept	0.07(0.44)	0.16	0.871
	Linear	-0.51(3.37)	-0.15	0.880
	Quadratic	0.05(3.25)	0.01	0.988
	Cubic	0.07(1.86)	0.036	0.972
	Quartic	-1.8(1.02)	-1.78	0.075
Rhyme	Intercept	0.70(0.43)	1.63	0.102
	Linear	4.16(3.30)	1.26	0.207
	Quadratic	4.03(3.18)	1.27	0.205
	Cubic	2.25(1.81)	1.24	0.215
	Quartic	0.84(1.01)	0.83	0.404
Experiment	Intercept	0.80(0.36)	2.24	0.022*
	Linear	5.51(2.74)	2.01	0.044*
	Quadratic	5.64(2.65)	2.13	0.033*
	Cubic	3.08(1.50)	2.05	0.040*
	Quartic	1.70(0.85)	2.01	0.045*
Onset * Experiment	Intercept	-1.79(0.62)	-2.89	0.004**
	Linear	-13.17(4.76)	-2.77	0.006**
	Quadratic	-12.77(4.60)	-2.78	0.005**
	Cubic	-7.61(2.62)	-2.90	0.004**
	Quartic	-4.34(1.45)	-2.98	0.003**
Rhyme * Experiment	Intercept	-1.42(0.61)	-2.32	0.020*
	Linear	-8.75(4.68)	-1.87	0.062
	Quadratic	-9.88(4.54)	-2.18	0.030*
	Cubic	-4.71(2.57)	-1.83	0.067
	Quartic	-2.57(1.45)	-1.76	0.078
		***p<.001, **p<.01, *p<.05		

Table 3.3: Results of second adult model with fixed effects of competitor type and experiment

further suggest that the type of experiment modulated the trajectory of looking proportions to all types of distractors. Finally, there were

significant interactions between the *onset* competitor and *experiment* on the intercept, linear, quadratic, cubic and quartic terms; as well as between the *rhyme* competitor and *experiment* on the intercept and quadratic terms and a trend towards significance on the linear, cubic and quartic terms. These results further suggest that *experiment* influenced the magnitude and trajectory of looking proportions to both phonological competitors. Looking proportions seem to be higher towards *onset* and *rhyme* competitors when real photographs are used (Experiment 1) as compared to line drawings (Experiment 2).

3.4 Discussion

In a previous study, Huettig & McQueen (2007) found increased looking proportions towards *onset* competitors when allowing participants enough time to silently label the images displayed before hearing the spoken word. However, when participants were only given 200ms to look at the images before hearing the spoken words, phonological effects were not observed. In contrast, results from Experiment 1 of this thesis revealed *onset* effects despite only using a pre-viewing time of 200ms. It was hypothesised that the differing results may stem from the fact that Huettig & McQueen (2007) used line drawings while Experiment 1 of this thesis made use of real photographs of objects. It is possible that silently retrieving the phonological code of line drawings may take longer than silent labelling of photographs. Experiment 2 was a replication of Experiment 1 replacing photographs with line drawings

in order to investigate whether the different modes of presentation may account for the differing results. As hypothesised, in the present experiment, adults did not display significantly higher looking proportions towards phonological competitors than towards *unrelated* distractors when presented with line drawings of objects and only given 200ms to look at the images before hearing the spoken word. The present findings replicate results by Huettig & McQueen (2007) and confirm the hypothesis that the differences in results between Experiment 1 of this thesis and the study by Huettig & McQueen (2007) may stem from the fact that the latter employed line drawings rather than real photographs of object.

In accordance with various previous studies comparing recognition of photographs and line drawings (Davies et al., 1978; Leder, 1996; Rossion & Pourtois, 2004; Tversky & Baratz, 1985), the present results demonstrate that adults take longer to extract information from line drawings than from photographs. Such findings contradict edge-based theories of object recognition (Grossberg & Mingolla, 1985; Marr, 1982; Marr & Nishihara, 1978) which propose that object shape is the main factor driving object recognition and that surface or texture properties do not further facilitate it. Instead, such theories predict that line drawings should be easier to recognise since they present the visual system with already preprocessed edges (Biederman & Ju, 1988). The present findings are, however, in accordance with image-based theories of object recognition (Tarr & Bülthoff, 1998) which suggest that

objects are processed by the viewer as a whole and that texture and colour information additionally aids object recognition.

In accordance with Experiment 1, the present experiment found that the similarity of the onset of the spoken word and the onset of the *rhyme* competitor modulates looking proportions towards phonological competitors in a visual world paradigm. Experiment 8 will further investigate this hypothesis.

Finally, the present findings have important implications on future studies in the field: When designing experiments using images of objects, researchers should carefully consider whether to use line drawings or photographs of objects depending on the hypotheses they are trying to test and be careful to take the mode of representation in mind when comparing results from different studies. If investigating phonological competition during spoken-word recognition - particularly in infants - it is advisable to use real photographs rather than line drawings. This aids participants in quickly extracting the relevant information necessary for object recognition which, in turn, is a prerequisite for extracting the phonological code for an object.

Chapter 4

Experiment 3: Separating *Onset* and *Rhyme* Effects

4.1 Introduction

Experiment 1 showed that adults fixated on *onset* competitors more than *unrelated* and *rhyme* competitors in a four-picture visual world paradigm. However, while there seemed to be a trend of adults preferentially fixating *rhyme* competitors as compared to unrelated distractors, this trend was not as clear as has been found in previous studies (e.g. Allopenna et al. (1998)). Furthermore, infants showed no preference for either type of phonologically related competitor over *unrelated* competitors.

There are several possible explanations why we did not find the complete phonological effects expected in adults and infants. One such pos-

sibility is that displaying the *onset* and *rhyme* distractors together in the same visual display may have lead to strong enough competition between the two that overshadowed the expected results.

Phonological *onset* effects are a well established phenomenon observed in adults whereas the presence of *rhyme* effects has been a lot more controversial. In Experiment 1, the fact that an *onset* competitor was among the images might have lead to reduced looking proportions to the *rhyme* competitor since participants' attention was drawn towards the much more salient *onset* competitor instead. Since *onset* effects seem to be a lot more robust than *rhyme* effects, the *onset* competitor might have won the competition for attention in a four picture display in which both phonological competitors compete with each other. Interestingly, Allopenna et al. (1998) have been able to reveal both *onset* and *rhyme* effects in a four-picture visual display. However, taking a closer look at their analysis reveals that their results in fact include a mixture of trials in which a *rhyme* competitor was presented with three unrelated distractors as well as trials in which a *rhyme* competitor was presented with an *onset* competitor and two unrelated distractors. It is impossible to distinguish whether *rhyme* effects were also observed in trials in which the two phonological competitors had to compete with each other or whether, in fact, the observed results are only due to to the subset of trials in which the *rhyme* competitor was the only phonological competitor.

In Experiment 3, we therefore separate *onset* and *rhyme* effects in

order to determine whether competition from the *onset* competitor may previously have overshadowed the weaker *rhyme* effect.

However, another explanation for the lack of a *rhyme* effect in Experiment 1 may have been the short pre-naming phase of only 200ms. As Huettig & McQueen (2007) argue, a pre-naming phase of more than 200ms is necessary in order to uncover phonological effects in spoken word recognition using a visual world paradigm. The rationale behind this idea is that participants need to first implicitly name the images in a visual display - thereby, activating the lexical representations of all the objects in the display. They can then compare these activated representations to the actual auditory input they encounter when they hear the spoken word. It is possible that the short pre-naming phase of only 200ms in Experiment 1 prevented participants from implicitly naming all the objects in the display before hearing the spoken word which may have prevented any attention being drawn to the *rhyme* competitor. For this reason, Experiment 3 will increase the pre-naming phase to one second for adults.

Finally, it is possible that *rhyme* effects in adults can only be observed when the two rhymes are phonologically very similar. Previous research has indicated that a word is more likely to activate its rhyme neighbour the more phonologically similar it is to this rhyme. For instance, Connine et al. (1993) used cross-modal priming experiments to demonstrate that nonwords which only differed in one or two linguistic features from a real word were able to activate words semantically related

to the real word. However, words that differed in more than two linguistic features were not able to elicit any priming effects. Analysis of phonological similarity scores of Experiment 1 of this thesis suggested that the phonological similarity between the first phoneme of a *rhyme* competitor and an *unrelated* distractor may have modulated the *onset* effect. Such findings imply that the *rhyme* competitor was in fact processed in Experiment 1 and that its phonological similarity to the spoken word influenced overall looking behaviour. Experiment 3 will investigate whether strong *rhyme* effects can only be elicited using a visual world paradigm with adults if the two rhymes are phonologically very similar. The most similar a pair of rhymes can be to each other is if its first phonemes differ only in terms of voicing (e.g. *pear- bear*). The present experiment will therefore compare trials in which the first phonemes of the rhyme pairs only differs in terms of voicing with trials in which they differ in terms of place, manner and voicing.

Changing the timing of stimulus presentation, reducing the number of images from four to two, separating onset and rhyme effects and manipulating rhyme similarity introduces a large number of changes in comparison to the previous experiment. If the combination of these changes leads to a much sharper *rhyme* effect, then following experiments will need to determine which of the different manipulations facilitated the occurrence of *rhyme* effects (see Experiment 4).

Similarly to adults, a direct competition between *onset* and *rhyme* competitors as well as the short pre-naming phase may have prevented in-

fant's attention from being directed to the phonologically related competitors over the unrelated distractors. Therefore, both phonological distractors will be separated and the pre-naming phase increased to two seconds for infants in Experiment 3. Furthermore, the current experiment will only be conducted with infants aged 30 months to exclude the possibility that infants in Experiment 1 were simply too young to display phonological competition in spoken-word recognition.

If the combination of these changes in fact leads to the occurrence of phonological effects in infants, then follow-up experiments will need to determine which of the different manipulations may be responsible for this observation.

The overall aim of Experiment 3 was therefore to determine whether separating *onset* and *rhyme* competitors would allow for phonological effects to become apparent in infants and for *rhyme* effects to become more clearly visible in adults.

4.2 Experiment 3a: Infants

4.2.1 Methods

Participants

Data from 37 infants was included in this study. Infant participants were native English speakers aged between 29.50 and 30.75 years (M = 30.09, SD = 0.30) who were recruited from monolingual British

households. Recruitment was conducted in the same manner as in Experiment 1. There were 17 females and 20 males. An additional three infants were excluded from analysis due to being fussy (2) or problems with calibrating their eyes on the eye-tracker (1). 13 participants did not complete the entire second block of the experiment due to getting fussy.

Design

In order to investigate the time course of looking proportions to images that are phonologically related or unrelated to target auditory words, eye movements were recorded in a visual world paradigm displaying two pictures. A two-picture design was chosen since this experiment removed any competition between *onset* and *rhyme* competitors and was only concerned with the competition between either type of phonologically related competitor and an *unrelated* distractor. The experiment consisted of two types of trials: **target absent** trials which served as experimental trials and **target present** trials which were used as filler trials. On **target absent** trials, the object that participants were instructed to look at was not present among the two pictures displayed on the screen. However, one phonological competitor (either *onset* or *rhyme* competitor) was shown together with an *unrelated* distractor that was neither phonologically nor semantically related to the target word. In a third condition, two *unrelated* distractors were displayed together in order to determine a baseline of looking behaviour in the

absence of any phonologically related competitors. This was done, to ensure that participants did not prefer one *unrelated* distractor over another and to be able to compare looking proportions to *onset* and *rhyme* competitors with looking proportions to completely unrelated distractors. For each trial, one of the two *unrelated* distractors was randomly chosen as the baseline. For *rhyme* trials, the *unrelated* distractor always had the same first phoneme as the *rhyme* competitor. This was done in order to minimise the influence of the first phoneme of the *unrelated* distractor on the observation of phonological effects (as was observed in Experiment 1). Ideally, *onset* and *unrelated* trials should have been similarly manipulated to ensure consistency across trial types. On **target present** trials, the object that participants were instructed to look at was among the two pictures displayed; together with one distractor object that was phonologically, visually and semantically unrelated to the target object. In total, there were 27 experimental trials (9 *onset*, 9 *rhyme* and 9 *unrelated* trial types) and 24 filler trials. Eye movements were recorded using a Tobii TX300 automated eye-tracker. Looking proportions per time bin to *onset* competitors, *rhyme* competitors and *unrelated* distractors served as the dependent variable.

Stimuli

A list of stimuli was created by extracting all monosyllabic words from the Oxford Communicative Development Inventories (CDI, Hamilton et al. (2000)). Only words that were imageable were further consid-

ered. Within the remaining imageable, monosyllabic words which are normally understood by infants at the age of 2 years, rhyme-pairs were defined. Remaining imageable, monosyllabic words were used to create onset-pairs. An additional set of bisyllabic words was used to create an additional rhyme and onset pair: parrot-carrot, parrot-pillow. Each word appeared as an *onset*, *rhyme* and *unrelated* distractor.). Remaining imageable, monosyllabic words were used to create **target absent** trials.

Each participant was presented with a different pseudo-randomised list (for an example see Table B.1). *Onset* and *rhyme* competitors were paired with the same spoken words and *unrelated* distractors to ensure that the only difference between the two types of trials was the visual object for the *phonologically* related competitor. Across trials, each object was presented an equal number of times. Every time an object was repeated, a different image of this object was presented. In order to avoid possible priming effects, there were always at least three trials in between trials that contained the same objects. In order to avoid any possible effects of coarticulation, sentences were created using the same recording for the first part of the sentence ("Look") and adding an isolated recording of the target word in the end. This resulted in spoken sentences such as "Look, mouse!" in which participants were unable to make any predictions about the spoken word simply from hearing the initial pronunciation of the word "Look".

Procedure

On each trial, participants were first presented with an attention getter in the middle of the screen. The attention getter comprised of a rotating twirl that lasted for 1.5s and was accompanied by a sparkling sound lasting one second. A two picture display appeared immediately after the offset of the attention getter and stayed on the screen for 5 seconds. The visual display was accompanied by an auditory sentence instructing participants to look at the target object (e.g. "Look cat"). The onset of the target word appeared 2s after the onset of the visual display. There was therefore a 2-second pre-naming phase and a 3-second post-naming phase (see fig. 4.1). Infants repeated the list twice. The two blocks were identical - however, in the second block, the position of the images was reversed to avoid any possible effects of looking preference to the left or the right side of the screen. Infants took a break between the two blocks which they spent playing with toys in order to keep them engaged.

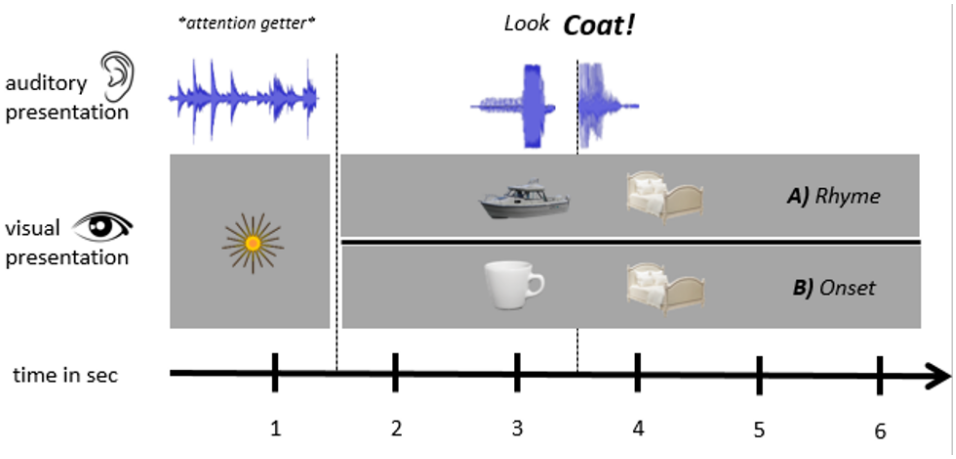


Figure 4.1: Example Infant Trial

Analysis

262 trials (16.38%) were excluded from analysis because they contained more than 75% track loss. Data was analysed from the onset of the target word to the end of the visual presentation (3000ms total). Looking proportions were calculated and statistical analyses carried out in the same way as in Experiment 1.

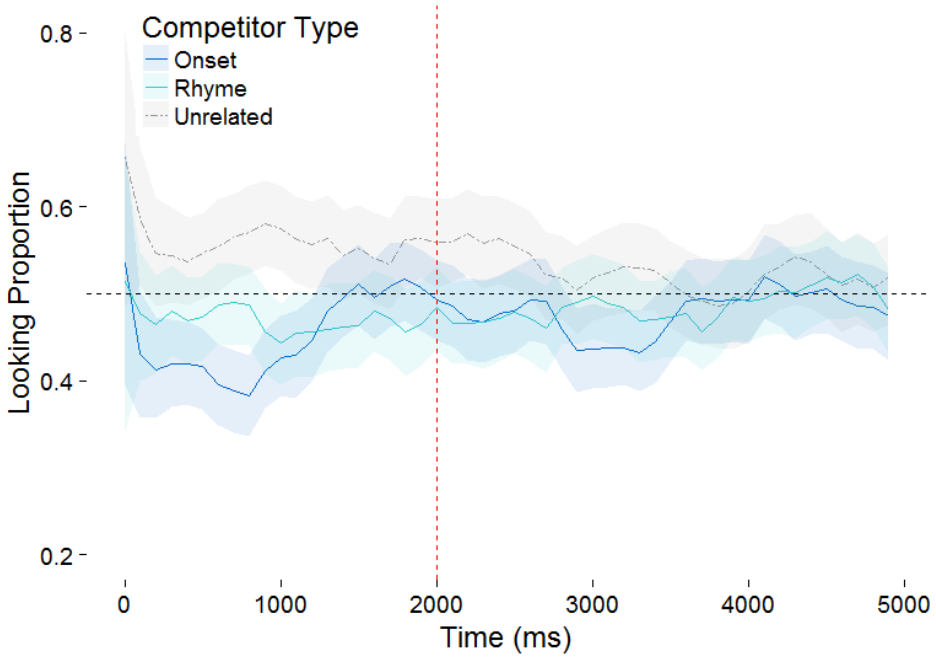


Figure 4.2: Overall Looking Proportions for the three different Conditions.

4.2.2 Results

Figure 4.2 displays the time course of looking proportions to *onset*, *rhyme* and *unrelated* competitors for the three different types of target

absent trials. Looking proportions towards *unrelated* competitors for all trial types were combined.

Growth Curve Analysis

The overall time course of looking proportions between 2000-5000ms after the onset of the visual display was modelled with fourth-order orthogonal polynomials and fixed effect of *competitor type* on all time terms. *Unrelated* distractor was treated as the baseline and parameters were estimated for *onset* and *rhyme* competitors. The model also included random effects of participants on the intercept, linear, quadratic and cubic time terms. Figure 4.3 shows the model between 2000 and 5000ms after onset of the visual display. The figure suggests that looking proportions were not higher towards phonologically related competitors than the *unrelated* distractor. The results of the statistical model are summarised in Table 4.1. Neither the intercept nor any of the linear, quadratic, cubic or quartic terms are significant for either the *onset* or the *rhyme* competitor.

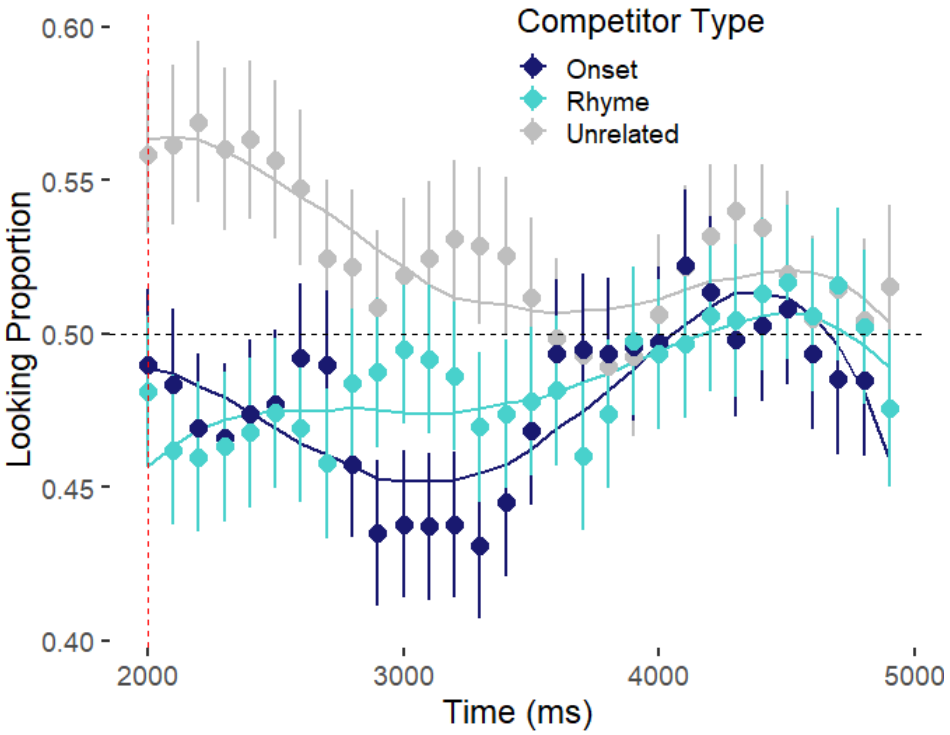


Figure 4.3: Growth curve analysis for infant data. Points represent data and lines display the model.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Onset	Intercept	-0.19(1.16)	-0.17	0.868
	Linear	0.27(11.29)	0.02	0.981
	Quadratic	0.23(8.99)	0.026	0.980
	Cubic	0.35(4.77)	0.07	0.941
	Quartic	-0.68(1.48)	-0.46	0.644
Rhyme	Intercept	-0.27(1.17)	-0.23	0.819
	Linear	0.81(11.35)	0.07	0.943
	Quadratic	0.43(9.04)	0.05	0.962
	Cubic	-0.60(4.79)	-0.12	0.901
	Quartic	0.18(1.48)	0.12	0.903
		***p<.001, **p<.01, *p<.05		

Table 4.1: Results of infant model with fixed effects of competitor type.

Figure 4.4 shows looking proportions to the three competitor types for individual target words. It can be seen that there is no clear tendency for phonological effects for any of the target words. One exception is trial **Lpear**: Here, a preference for the *rhyme* competitor can be suspected. During this trial, infants heard the sentence "Look pear!" while they saw the images of a bear and a ball.

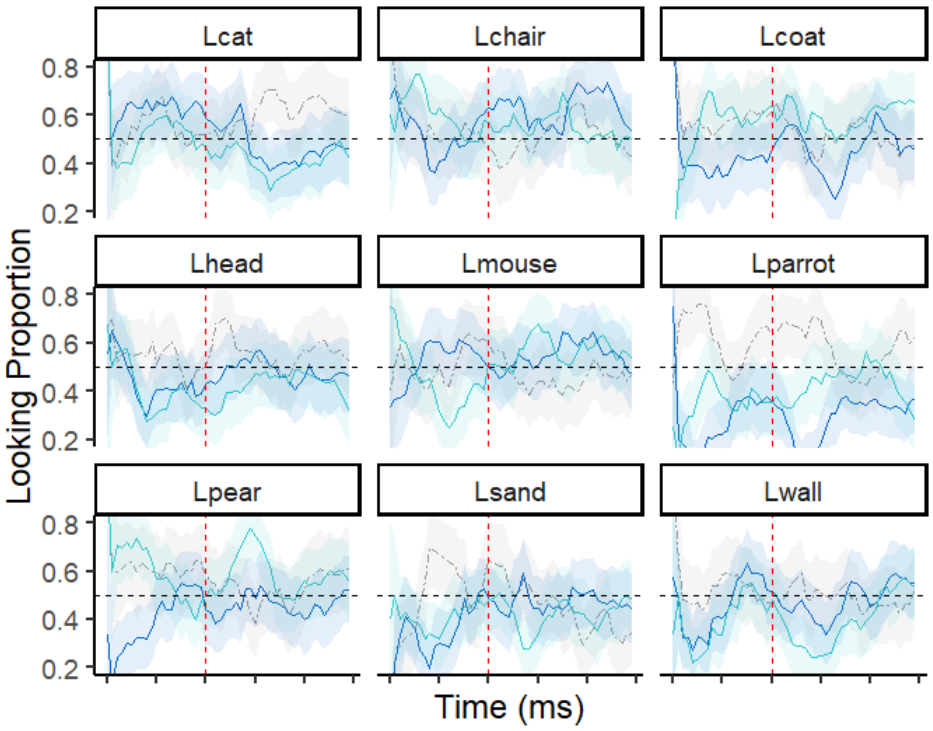


Figure 4.4: Overview of looking proportions for individual trials.

4.2.3 Discussion: Infant Results

The present results indicate that infants do not preferentially look at phonologically related competitors over *unrelated* distractors in a preferential looking paradigm. Even though *onset* and *rhyme* competitors

were separated and never occurred together in the present experiment and infants were given two seconds to look at the images before hearing the target word, 30-month old infants did not prefer looking at either of the two phonologically related competitors over the unrelated distractors. In line with Experiment 1, such findings seem to suggest that when processing spoken language, 2-year-olds' attention is not driven by phonological factors but rather by factors not captured in the present experiments such as visual or semantic similarity. Infants, thus, don't seem to make use of either incremental or continuous strategies of spoken-word recognition.

However, the present findings are not in line with previous results by Swingley et al. (1999) who showed that 2-year old infants take longer to look at a target word when it is paired with an *onset* competitor and Chow et al. (2017) who demonstrated early looking preferences for *onset* competitors in a 4-picture visual world paradigm.

There are several possible explanations for the present lack of preference for phonological competitors. Firstly, it is possible that by choosing to use a set of monosyllabic words which either rhymed or started with the same sound, we put some constraints on our experimental setup. Due to the small size of monosyllabic rhyme pairs that are understood by 2-year-old infants, some compromises had to be made when designing the stimuli list. For instance, given the limited amount of words available, it was not possible to control for effects of animacy or frequency of the objects shown in the visual display. Notable are particularly any

trials containing "bear". The trial **pear**: *bear - ball* is the only trial that seemed to produce a *rhyme* effect. While one could argue that this is due to the relatively close phonological similarity between pear and bear (unlike other rhyme pairs in this study, they only differ in terms of voicing on the first phoneme), a much simpler explanation would be that infants merely preferred looking at the animate object bear over the inanimate object ball. However, it might not only be animacy that drives infants looking behaviour but additionally the "likeability" of an object. An example for this might be seen in the trial **parrot**: *pillow - cookie*. While pillow here acts as an *onset* competitor, cookie is the *unrelated* distractor. This is a problematic case since infants' attention might naturally be drawn more towards the appealing cookie which they might associate with reward rather than the pillow which they might associate with having to go to sleep. While these are mere speculations, the present results show that infants consistently preferred looking at the unrelated object "cookie" over the phonological competitors (pillow or parrot). In order to minimise such effects of likeability, each stimulus could have been used as *rhyme*, *onset* and *unrelated* distractor by keeping the images constant while only changing the spoken word.

Future studies on phonological competition in spoken word recognition in infants should therefore make sure to carefully control for factors such as animacy, word frequency or object familiarity and "likeability" to ensure that observed effects are due to phonological processing rather

than other artefacts guiding infants' attention.

One solution to the problems observed in the present study could be to use pseudowords as spoken target words in order to increase the set of words available for experimental manipulation. This may make it easier to control for factors such as animacy or word frequency. Experiment 6 will therefore make an attempt at investigating phonological competition in infants using pseudowords in a visual world paradigm. Aside from increasing the range of words available for setting up a study, pseudowords may also have the benefit of not activating lexical information in the same way that real words do. It is this strong activation of lexical information that may have prevented infants from displaying any smaller phonological effects upon hearing real spoken words.

Finally, despite using a considerably larger amount of trials for Experiment 3 as compared to Experiment 1, it is possible that the present experiment may not have had enough statistical power in order to be able to detect relatively small effects of phonological competition during spoken-word recognition in infants.

4.3 Experiment 3b: Adults

Experiment 3b was similar to Experiment 3a but was conducted with adults rather than infants in order to examine how manipulating the competition between *onset* and *rhyme* competitors, increasing previewing time of the visual display and reducing the number of images

from four to two images influences language-mediated visual attention in adults. Furthermore, Experiment 3b aimed to show that it is possible to reveal effects of phonological competition during spoken-word recognition with the setup used with infants in Experiment 3a.

4.3.1 Methods

Participants

Data from 26 adult participants was included in the analysis for this study. One additional participant had to be excluded from analysis due to the eye-tracker losing their eye. Adult participants were native English speakers aged between 18.32 and 33.72 years ($M = 22.70$, $SD = 4.16$) who were recruited from the University of Oxford. There were 18 females and 8 males. All adult participants reported normal or corrected-to-normal vision and no history of language or hearing impairments.

Design

The design of Experiment was identical to Experiment 3a. However adults were presented with an extended set of stimuli resulting in 58 experimental trials (29 *onset* and 29 *rhyme* trials) and 84 filler trials (see appendix B for an example trial list). All additional stimuli were monosyllabic and the *rhyme* trials of the additional set of stimuli was split into two conditions: In the *Similar* condition, the first phoneme

of the *rhyme* competitor differed from the first phoneme of the spoken word only in terms of voicing; in the *Different* condition, the two phonemes differed in at least two features. Finally, the stimuli set for adults did not contain any filler trials in which two *unrelated* distractors were paired with each other. This was done since it was believed that under such conditions, adults would show no preference for either distractor displaying looking proportions of approximately 50% for each *unrelated* distractor. The same could not be assumed for infants whose looking behaviour tends to be less predictable than for adults.

Stimuli

Adult participants were presented with the same stimuli as infants in Experiment 3a plus an additional set of stimuli described above.

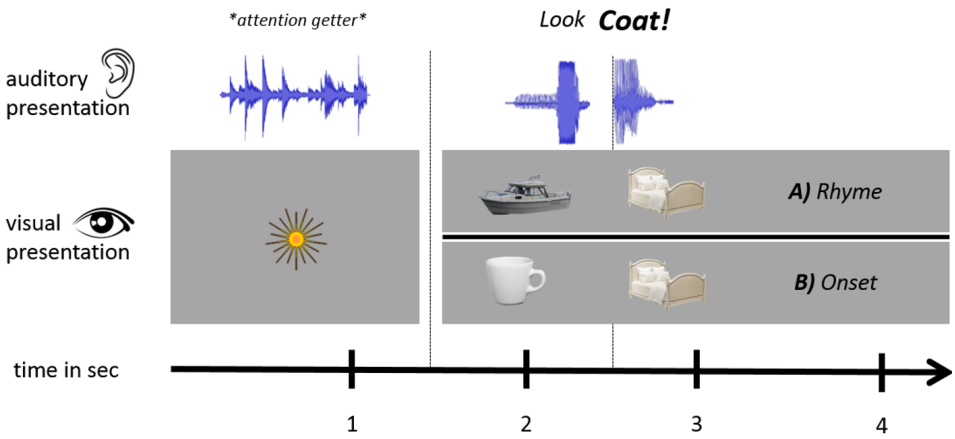


Figure 4.5: Example Adult Trial

Procedure

The procedure in Experiment 3b was identical to Experiment 3a, however, adults were only given one second of pre-naming phase before hearing the target word and only saw the images for an additional two seconds after target word onset (see fig. 4.5). Furthermore, adults only took a short one minute break between the two blocks.

Analysis

No trials were excluded from analysis due to track loss. The rest of the analysis was identical to Experiment 3a.

4.3.2 Results

Figure 4.6 displays the time course of looking proportions to the two pictures averaged across all adult participants and trials starting from the onset of the spoken word. Looking proportions towards *unrelated* competitors for all trial types were combined. The plot indicates increased looking proportions to the *onset* competitor between 250-750ms after target word onset while looking proportions to the *rhyme* competitor seem to increase starting at approximately 500ms after target word onset.

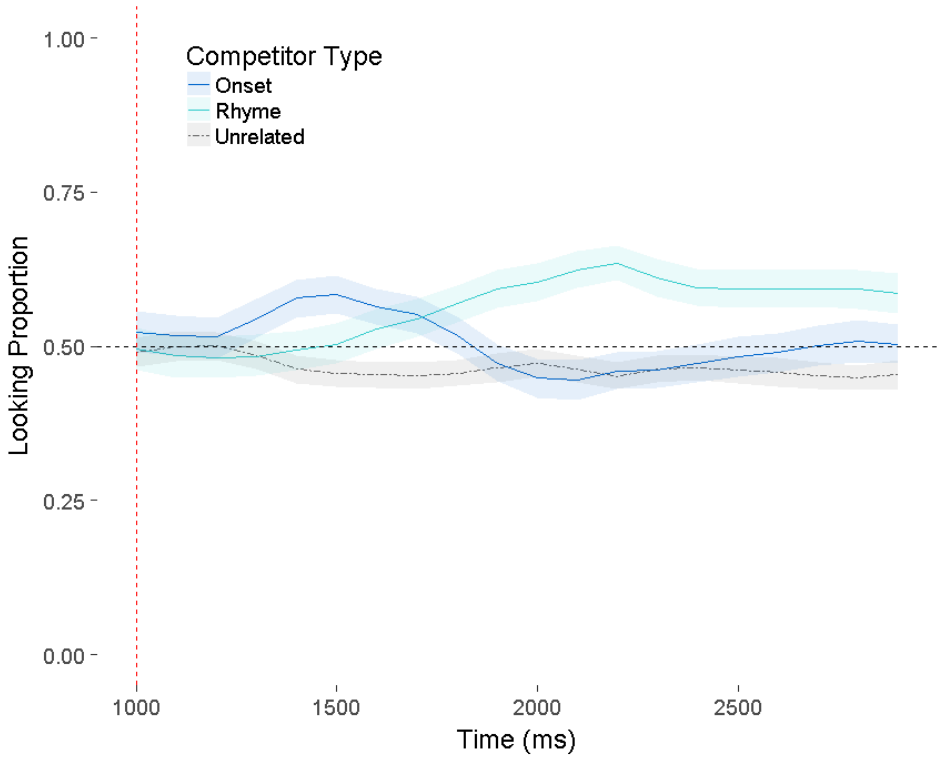


Figure 4.6: Overall looking proportions across all conditions.

Growth Curve Analysis

The overall time course of looking proportions between 1000-3000ms after the onset of the visual display was modelled with fourth-order orthogonal polynomials and fixed effect of *competitor type* on all time terms. Unrelated distractors were combined and treated as the baseline and parameters were estimated for *onset* and *rhyme* competitors. The model also included random effects of participants on all time terms and random effects of auditory stimulus nested under participant random effects on all time terms.

Figure 4.7 shows the model between 1000 and 3000ms after onset of the

visual display. The figure suggests early increased looking proportions to the *onset* competitor starting approximately 200ms after target word onset as well as increased looking proportions to the *rhyme* competitor starting around 500ms after onset of the auditory word. The results of the statistical model are summarised in Table 4.2. There were significant intercepts for the *onset* as well as *rhyme* competitors showing that looking proportions to both phonological competitors were generally higher than for *unrelated* distractors. The significant linear, quadratic, cubic and quartic terms for *onset* as well as *rhyme* competitors suggest that the trajectory of looking times differed between both phonological competitors and *unrelated* distractors.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Onset	Intercept	-1.42(0.38)	-3.79	<.001***
	Linear	12.15(2.90)	4.19	<.001***
	Quadratic	-10.19(2.43)	-4.19	<.001***
	Cubic	5.76(1.41)	4.09	<.001***
	Quartic	-1.35(0.51)	-2.63	0.009**
Rhyme	Intercept	1.38(0.38)	3.68	<.001***
	Linear	-7.46(2.90)	-2.57	0.010*
	Quadratic	7.86(2.44)	3.22	0.001**
	Cubic	-5.23(1.41)	-3.71	<.001***
	Quartic	1.69(0.51)	3.30	<.001***
			***p<.001, **p<.01, *p<.05	

Table 4.2: Results of first adult model with fixed effects of competitor type.

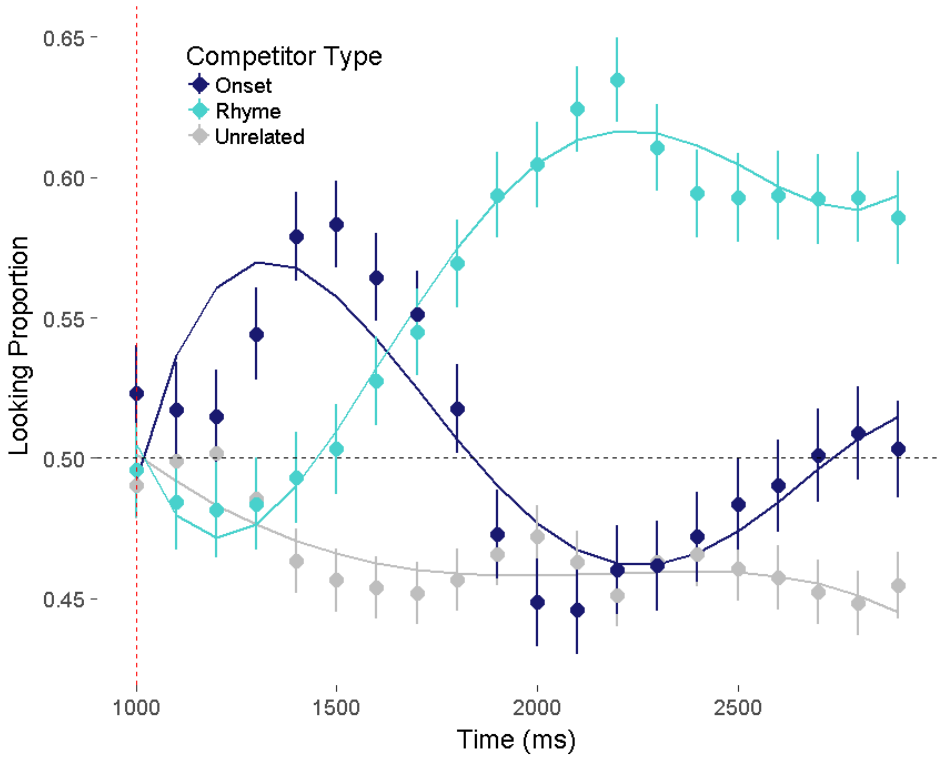


Figure 4.7: Growth curve analysis for adult data. Points represent data and lines display the model.

T-Tests

While the growth curve analysis above clearly displays the pattern of early increased looking proportions towards *onset* competitors followed by later and larger increased looking proportions towards the *rhyme* competitor, its results have to be taken with caution since the baseline for this growth curve analysis was the average of looking proportions for unrelated distractors in both rhyme and onset trials. Since the present experiment was a two-picture paradigm, increased looking proportions to the phonological competitor consequently lead to decreased looking proportions to the *unrelated distractor*. It is for this

reason that looking proportions to the *unrelated* distractor are not at chance level where they would be expected to be if participants were choosing between two completely neutral *unrelated distractors*. T-tests were therefore conducted to compare looking proportions to *onset* and *rhyme* competitors to a chance level of 0.5.

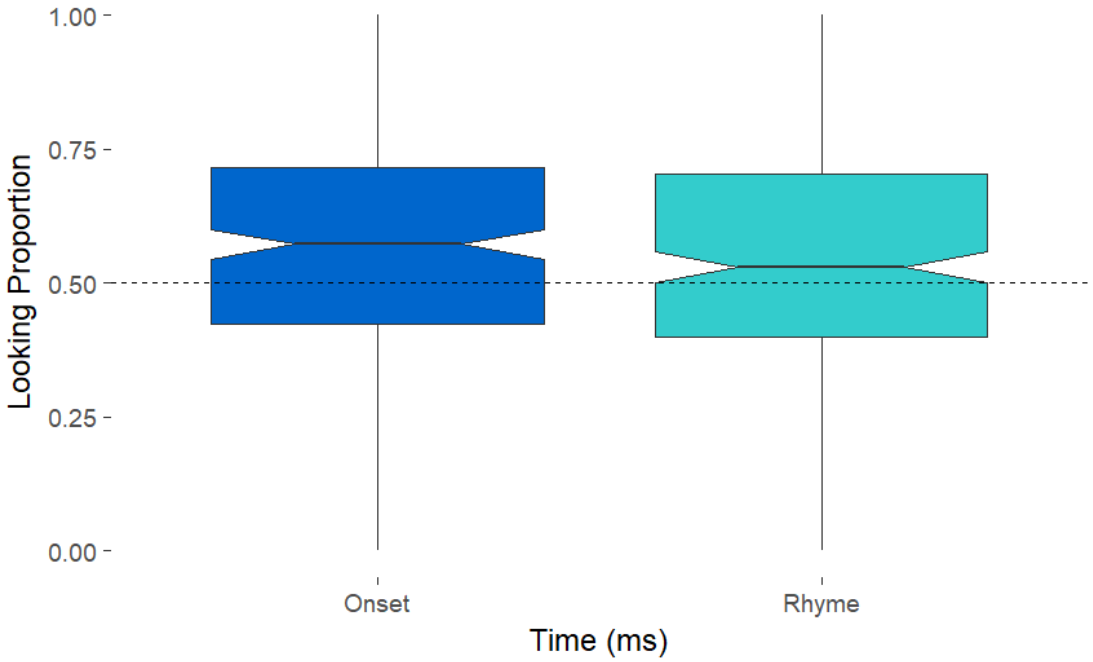


Figure 4.8: Comparison of looking proportions to *onset* and *rhyme* competitors to chance level of 0.5.

A one-sampled t-test was run between looking proportions to *onset* competitors and chance level of 0.5 for a time window between 200-700ms after onset of the target word. Mean looking proportions (0.557) to *onset* competitors were significantly higher than chance level ($t(5537) = 8.752$, $p < 0.001$, $d = 0.12$). A one-sampled t-test was run between looking proportions to *rhyme* competitors and chance level

of 0.5 for a time window between 300-1000ms after onset of the target word. Mean looking proportions (0.542) to *rhyme* competitors were significantly higher than chance level ($t(7595) = 7.450$, $p < 0.001$, $d = 0.09$). Figure 4.8 displays box plots comparing looking proportions to *onset* and *rhyme* competitors with chance level.

Comparison of Conditions

In order to determine whether the magnitude of the *rhyme* effect differed between the *Similar* and *Different* condition, looking proportions to the *rhyme* competitor were modelled with third-order orthogonal polynomials and fixed effect of *Condition* on all time terms. The *Different* condition was treated as the baseline and parameters were estimated for the *Similar* condition. The model also included random effects of participants on all time terms.

Figure 4.9 shows the model between 1000 and 3000ms after onset of the visual display. The figure suggests that while looking proportions to the *rhyme* competitor increase earlier in the *Different* condition, they have a larger peak and last longer in the *Similar* condition. The results of the statistical model are summarised in Table 4.3. There was a significant intercept for *Condition* showing that looking proportions were generally higher in the *Similar* than the *Different* condition. None of the linear, quadratic or cubic terms were significant suggesting that the general trajectory of looking times did not differ between the two conditions.

Fixed Effects	Model Terms	Est. (SE)	*t*	*p*
Condition	Intercept	0.57(0.25)	2.27	0.023*
	Linear	-1.80(1.87)	-0.96	0.335
	Quadratic	1.85(1.41)	1.31	0.190
	Cubic	-0.41(0.68)	-0.61	0.544
		***p<.001, **p<.01, *p<.05		

Table 4.3: Results of second adult model comparing looking proportions to *rhyme* competitors with fixed effect of condition.

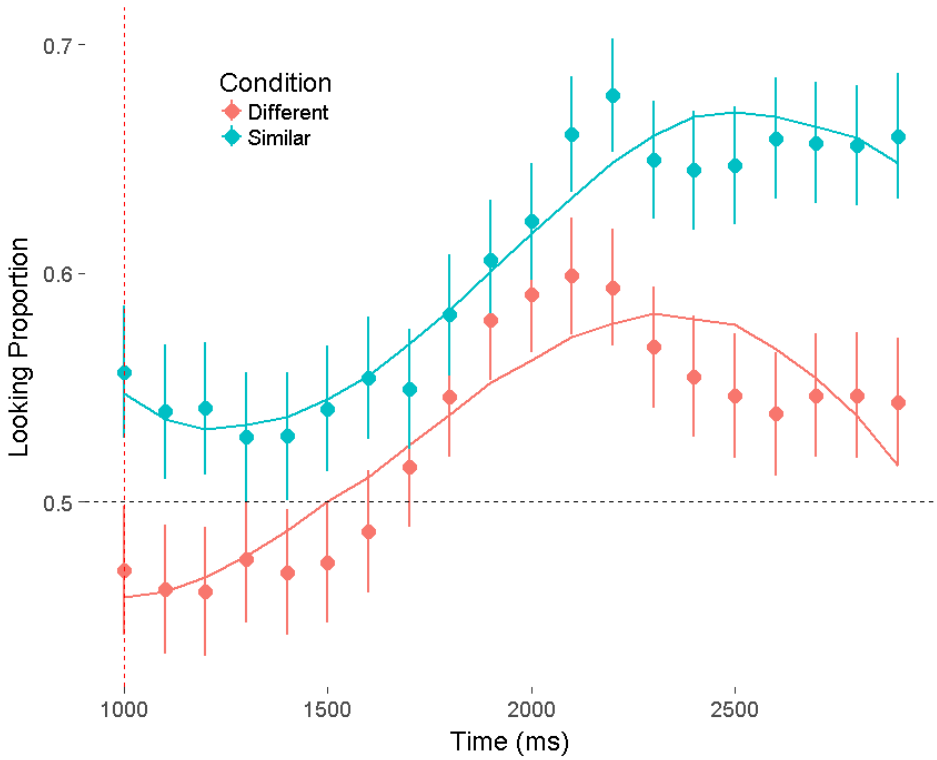


Figure 4.9: Growth curve analysis comparing looking to *rhyme* competitors for the two conditions. Points represent data and lines display the model.

4.3.3 Discussion

Separating *rhyme* and *onset* competitors as well as increasing the pre-naming phase to one second lead to increased looking proportions to *onset* competitors around 200-900ms after target word onset and increased looking proportions to *rhyme* competitors starting around 500ms after target word onset. As opposed to Experiment 1, the *rhyme* effect was very clear when *rhyme* and *onset* competitors were not presented together in the same visual display. It is possible that in Experiment 1, the presence of an *onset* competitor in fact suppressed activation of the *rhyme* competitor which may support the hypothesis that the clear *rhyme* effects observed in Allopenna et al. (1998) mainly stem from trials in which *rhyme* competitors were only presented together with *unrelated* distractors.

However, it is not possible to determine whether the present results stem from the lack of a direct competition between *onset* and *rhyme* competitors or in fact from the increased pre-naming phase of one second. A follow-up experiment is therefore needed in order to evaluate whether *rhyme* effects remain observable with a shorter or no pre-naming phase at all. Experiment 4 will address this question.

While results from Experiment 1 seemed to suggest that adults make use of incremental strategies when processing spoken-words, the present findings seem to indicate otherwise. Despite the *rhyme* competitor not sharing an initial phoneme with the spoken-word, it does not become excluded as a possible lexical candidate as indicated by the strong

rhyme effect observed here. Adults may use differing processing strategies depending on the information they are provided with. It may be the case that when given a relatively short pre-naming phase or when *onset* and *rhyme* competitor are presented simultaneously, they may make use of incremental processing strategies. On the contrary, when given a longer time to inspect visual stimuli before hearing the spoken word or when a *rhyme* competitor is presented separately from any *onset* competitors, they may make use of more continuous processing strategies as presented by the TRACE model (McClelland & Elman, 1986).

It should be noted that the effect size observed in Experiment 3b was very low which has further implications on the lack of findings in Experiment 3a. It is possible that Experiment 3a may not have had enough statistical power in order to be able to reveal the relatively small phonological effects that were predicted for infants.

Furthermore, looking proportions to *rhyme* competitors were higher and lasted for longer in the *Similar* condition in which the first phonemes of the spoken word and the *rhyme* competitor differed only in terms of voicing, than in the *Different* condition where they different in terms of place, voice and manner. These findings suggests that the amount of phonological similarity at the beginning of a word influences phonological competition during spoken-word recognition in adults and is in line with previous findings regarding the effect of linguistic similarity on cross-modal priming (Connine et al., 1993). It remains to be

determined whether the same is true for 2-year-old infants. Experiment 6 will therefore investigate looking proportions to objects when infants hear a mispronounced rhyme that either differs in its first phoneme from one of the objects displayed on the screen only in terms of voicing or in terms of place, manner and voicing.

Chapter 5

Experiment 4: Removing the Pre-naming Phase

5.1 Introduction

Experiments 1 and 2 demonstrated that, contrary to findings by Huettig & McQueen (2007), looking proportion towards *onset* competitors are higher than towards *unrelated distractors* when allowing participants only 200ms to examine a visual display before hearing an accompanied spoken word. However, looking proportions towards *rhyme* competitors seemed to be only slightly increased and did not produce clear significant results. It was hypothesised that this might be due to the short pre-naming phase or because *onset* and *rhyme* competitors were competing with each other in the same visual display which may lead the stronger *onset* effect to overshadow *rhyme* effects. In line with this

hypothesis, Experiment 3 demonstrated that with a longer pre-naming phase and by separating *onset* and *rhyme* competitors, looking proportions to both types of phonological competitors were significantly increased. However, it was not clear whether this was due to the increased pre-naming time or due to separating the two competitors.

In order to further investigate these findings, the aim of Experiment 4 was to determine whether *rhyme* and *onset* effects can be observed in a visual world paradigm when participants are not given any time to look at the images before hearing the target word. It was hypothesised that the relatively small *rhyme* effect in Experiment 1 did in fact stem from a direct competition between *rhyme* and *onset* competitor and not from the relatively short pre-naming phase of 200ms. It was therefore predicted that entirely removing the pre-naming phase for the current experiment would still allow for *rhyme* effects to be observed as long as *rhyme* competitors were presented separately from *onset* competitors.

5.2 Methods

5.2.1 Participants

26 adults took part in this study. Adult participants were native English speakers aged between 18.11 and 38.92 years ($M = 23.81$, $SD = 5.72$) who were recruited from the University of Oxford. There were 16 females and 10 males. All participants reported normal or corrected-to-normal vision and no history of language or hearing

impairments.

5.2.2 Design

The design was identical to Experiment 3b.

5.2.3 Stimuli

The stimuli were identical to Experiment 3b.

5.2.4 Procedure

The procedure was identical to Experiment 3b apart from the exact timing for the onset of visual and auditory stimuli. In this study, participants first saw an attention getter for 1s which was followed by a sentence such as "Look, boat!" (see Figure 5.1). Visual stimuli were presented immediately at the offset of the spoken target word. This setup prevented participants from silently labelling any of the images while hearing the spoken word and allowed investigating whether participants may use different processing strategies as compared to Experiment 3 where they were given one second to silently label the images before hearing the target word.

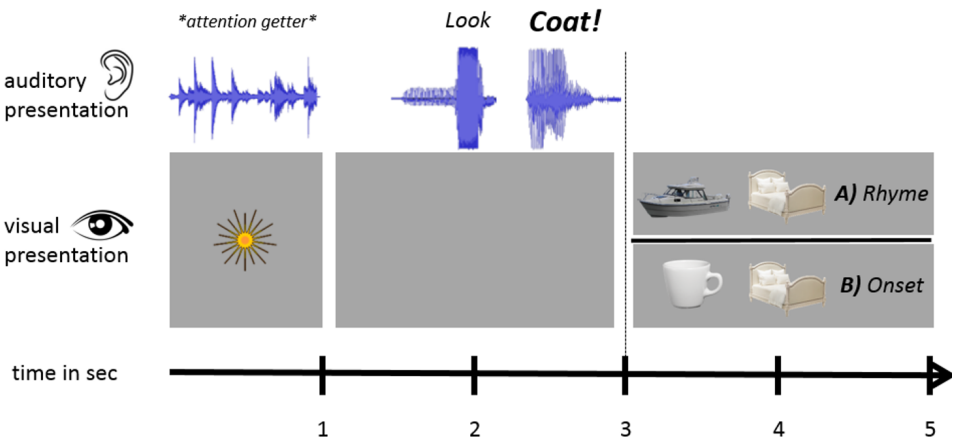


Figure 5.1: Example Trial

5.2.5 Analysis

Analysis was identical to Experiment 3b.

5.3 Results

Figure 5.2 displays the time course of looking proportions to *onset*, *rhyme* and *unrelated* competitors for the three different types of target absent trials. Initial inspection suggests that participants show increased looking proportions towards the *rhyme* competitor while looking proportions towards the *onset* competitor seem to be around chance level.

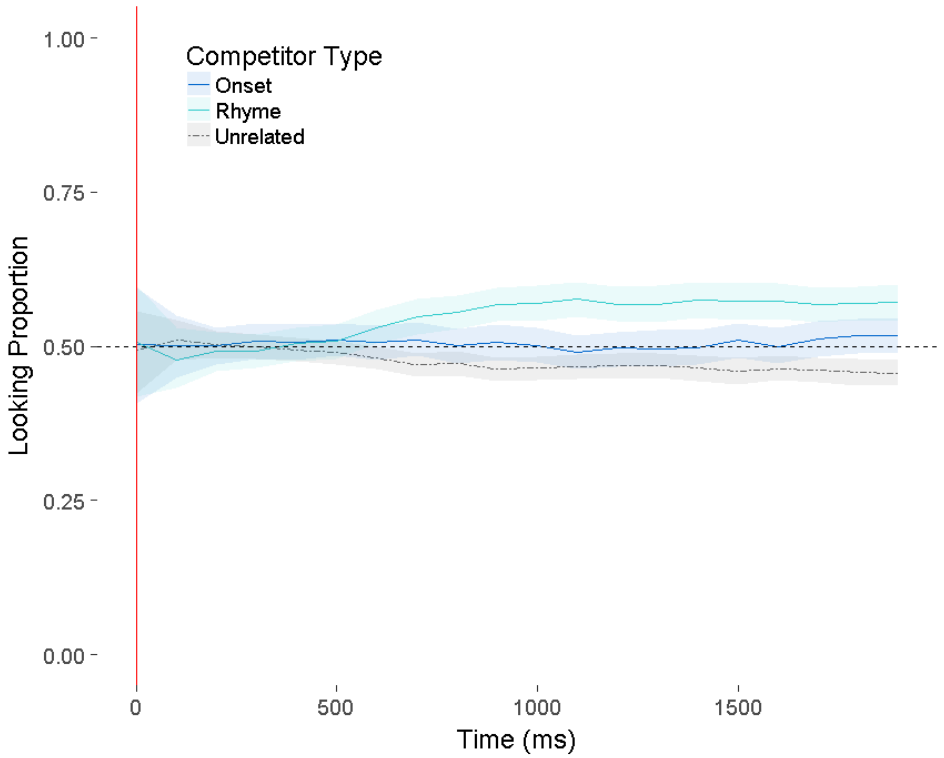


Figure 5.2: Overall looking proportions across all conditions.

5.3.1 Growth Curve Analysis

The overall time course of looking proportions between 0-2000ms after the target word offset was modelled with fourth-order orthogonal polynomials and fixed effect of *competitor type* on all time terms. Unrelated distractors were combined and treated as the baseline and parameters were estimated for *onset* and *rhyme* competitors. The model also included random effects of participants on all time terms.

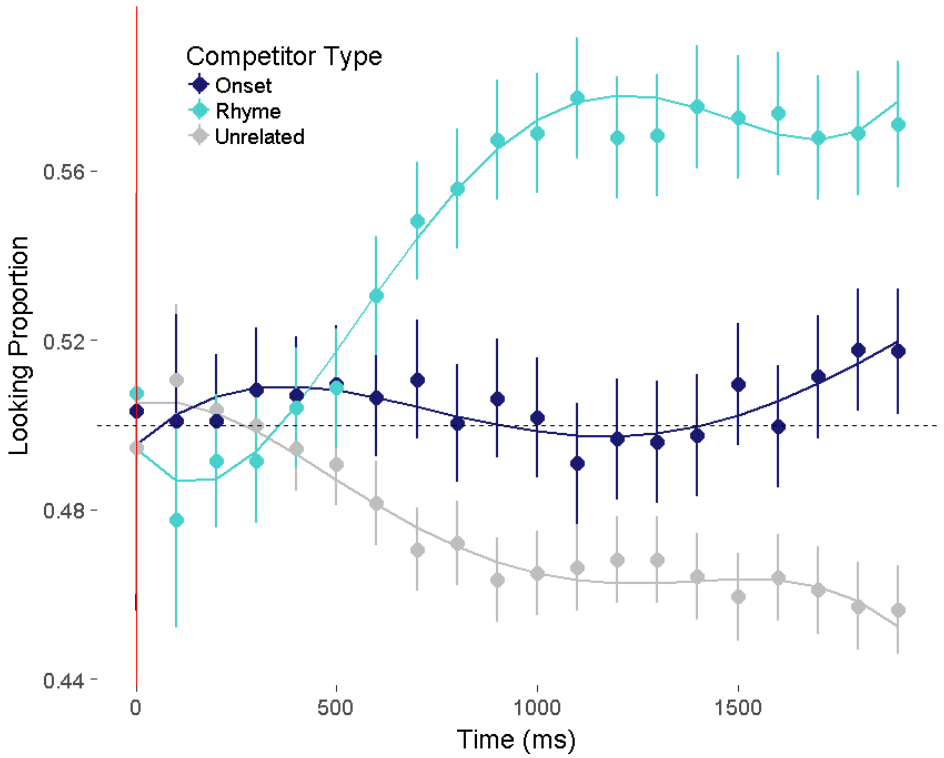


Figure 5.3: Growth curve analysis for adult data. Points represent data and lines display the model.

Figure 5.3 shows the model between 0 and 2000ms after target word offset. The figure suggests that looking proportions towards the *onset competitor* are around chance level throughout the entire displayed period. The figure further suggests increased looking proportions to the *rhyme* competitor starting around 500ms after offset of the auditory word. The results of the statistical model are summarised in Table 5.1.

Fixed Effects	Model Terms	Est. (SE)	*t*	*p*
Onset	Intercept	0.12(0.02)	5.89	<.001***
	Linear	0.31(0.11)	2.85	0.004**
	Quadratic	-0.03(0.11)	-0.29	0.776
	Cubic	0.09(0.10)	0.86	0.390
	Quartic	0.03(0.09)	0.34	0.730
Rhyme	Intercept	0.28(0.02)	14.16	<.001***
	Linear	0.83(0.11)	7.43	<.001***
	Quadratic	-0.32(0.11)	-2.78	0.005**
	Cubic	-0.07(0.10)	-0.72	0.474
	Quartic	0.20(0.09)	2.17	0.030*
		***p<.001, **p<.01, *p<.05		

Table 5.1: Results of first adult model with fixed effect of competitor type.

There were significant intercepts for the *onset* as well as *rhyme* competitors showing that looking proportions to both phonological competitors were generally higher than for *unrelated* distractors. The significant linear term for *onset* competitors suggests that the trajectory of looking proportions slightly differed between *onset competitors* and *unrelated* distractors. However, looking proportions to the *unrelated* distractors are not at chance level since they were derived by averaging looking proportions when *unrelated* distractors were presented together with either *onset* or *rhyme* competitors. None of the quadratic, cubic or quartic terms were significant for the *onset* competitor suggesting that overall its trajectory of looking proportions might be quite similar to the *unrelated* distractors. The linear, quadratic and quartic terms for the *rhyme* competitors suggest that the trajectory of looking propor-

tions differed between *rhyme* competitors and *unrelated* distractors.

T-Tests

In order to eliminate the problem that looking proportions towards the *unrelated* distractors in the growth curve analysis above were not at chance level, one-sampled t-test were run to compare looking proportions to phonological distractors to chance level. A one-sampled t-test was run between looking proportions to *onset* competitors and chance level of 0.5 for a time window between 200-700ms after onset of the visual display. Mean looking proportions (0.506) to *onset* competitors were not significantly different from chance level ($t(2695) = 0.671$, $p = 0.502$, $d = 0.004$). A one-sampled t-test was run between looking proportions to *rhyme* competitors and chance level of 0.5 for a time window between 300-1000ms after onset of the visual display. Mean looking proportions (0.588) to *rhyme* competitors were significantly higher than chance level ($t(1841) = 7.727$, $p < 0.001$, $d = 0.145$). Figure 5.4 displays box plots comparing looking proportions to *onset* and *rhyme* competitors with chance level.

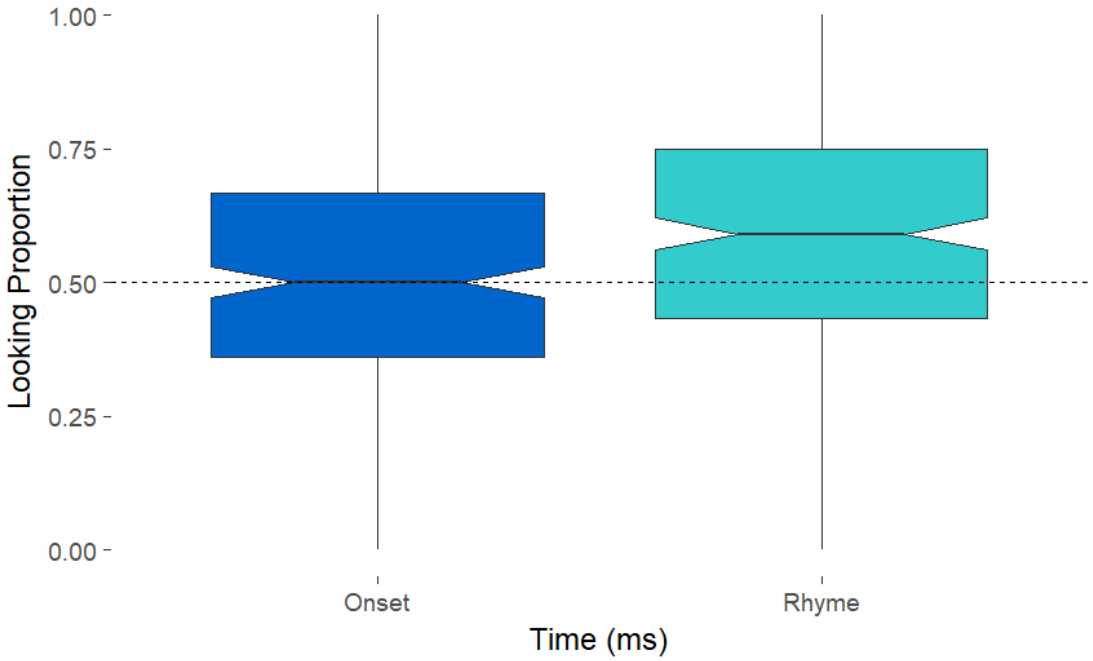


Figure 5.4: Comparison of looking proportions to *onset* and *rhyme* competitors to chance level of 0.5.

5.3.2 Comparison with Experiment 3b

In order to compare results between Experiment 3b and Experiment 4, the overall time course of looking proportions between 0-2000ms after the offset of the auditory word was modelled with fourth-order orthogonal polynomials and fixed effects of *experiment* and *competitor type* on all time terms. Unrelated distractors were combined and treated as the baseline and parameters were estimated for *onset* and *rhyme* competitors. Experiment 3b was treated as baseline and parameters were estimated for Experiment 4. The model also included random effects of participants on all time terms.

Figure 5.5 shows the model between 0 and 2000ms after target word offset. The figure suggests that an early increase in looking proportions towards the *onset* competitor when participants were given one second to examine the images before hearing the target word while this effect seemed to disappear with no pre-naming time given. Similarly, the effect of increased looking proportions towards the *rhyme* competitor seems to be lower for Experiment 4 than for Experiment 3b. The results of the statistical model are summarised in Table 5.2. There were significant intercepts for the *onset* as well as *rhyme* competitors showing that looking proportions to both phonological competitors were generally higher than for *unrelated* distractors. The significant linear, quadratic, cubic and quartic terms for *onset* and *rhyme* competitors suggests that the trajectory of looking proportions generally differed between phonological competitors and *unrelated* distractors. Finally, there were significant interactions between *experiment* and *competitor* type on the intercept and all time terms suggesting that the amount of pre-naming time participants were given significantly affected the amplitude as well as trajectory of looking proportions to both types of phonological competitors.

Fixed Effects	Model Terms	Est. (SE)	*t*	*p*
Onset	Intercept	-1.4(0.38)	-3.78	<.001***
	Linear	12.15(2.90)	4.18	<.001***
	Quadratic	-10.19(2.44)	-4.18	<.001***
	Cubic	5.76(1.41)	4.09	<.001***
	Quartic	1.35(0.51)	-2.63	0.009**
Rhyme	Intercept	1.38(0.38)	3.67	<.001***
	Linear	-7.46(2.91)	-2.57	0.010*
	Quadratic	7.86(2.44)	3.22	0.001**
	Cubic	-5.23(1.41)	-3.70	<.001***
	Quartic	1.69(0.51)	3.29	<.001***
Experiment	Intercept	-0.11(0.22)	-0.52	0.608
	Linear	0.92(1.67)	0.55	0.583
	Quadratic	-0.52(1.41)	-0.37	0.7111
	Cubic	0.14(0.81)	0.18	0.860
	Quartic	0.02(0.30)	0.07	0.944
Onset * Experiment	Intercept	1.54(0.38)	4.09	<.001***
	Linear	11.83(2.90)	-4.07	<.001***
	Quadratic	10.16(2.44)	4.16	<.001***
	Cubic	-5.68(1.41)	-4.01	<.001***
	Quartic	1.38(0.52)	2.65	0.008**
Rhyme * Experiment	Intercept	1.10(0.38)	-2.92	0.004**
	Linear	8.29(2.91)	2.85	0.004**
	Quadratic	8.17(2.44)	-3.35	<.001***
	Cubic	5.16(1.42)	3.64	<.001***
	Quartic	1.38(0.52)	2.65	0.008**
		***p<.001, **p<.01, *p<.05		

Table 5.2: Results of second model with fixed effects of competitor type and experiment.

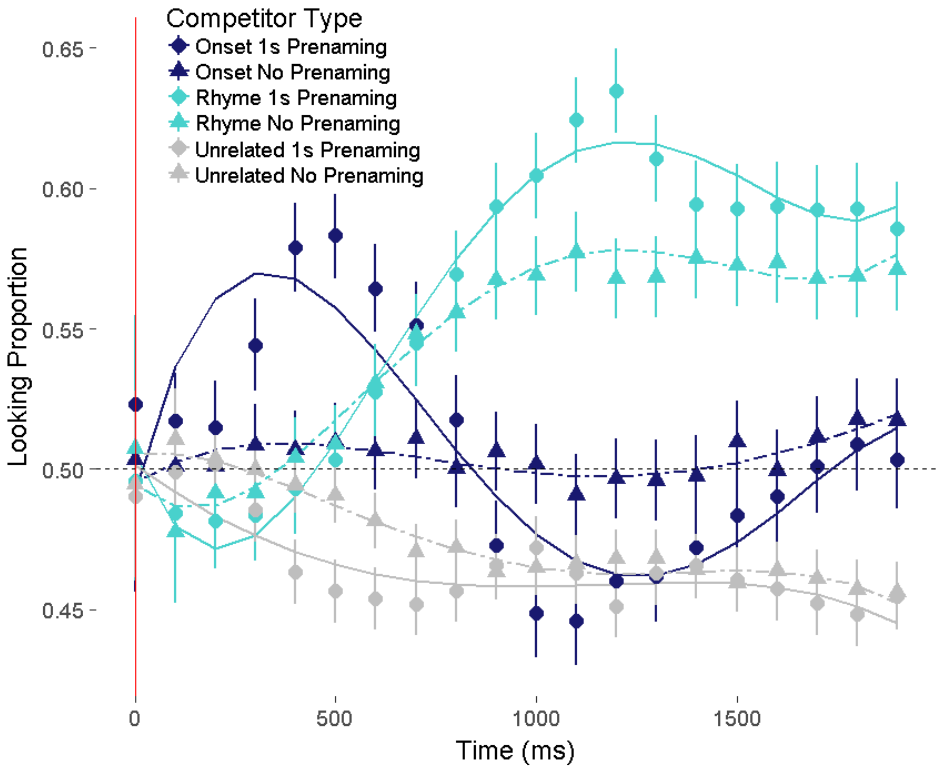


Figure 5.5: Growth curve analysis for adult data comparing looking proportions to *onset* and *rhyme* competitors depending on the amount of pre-naming time given. Points represent data and lines display the model.

ANOVA

A two-way ANOVA was conducted for looking proportions between 0-2000ms after target word offset to examine the effect of *Experiment* and *Competitor Type* on looking proportions without requiring *unrelated* distractors as a baseline. There was a significant main effect of *Experiment* on looking proportions ($F(1,\ 33184) = 63.24,\ p < 0.001,\ \eta^2 < 0.001$) and a significant main effect of *Competitor Type* on looking proportions ($F(1,\ 33184) = 99.11,\ p < 0.001,\ \eta^2 < 0.001$). Furthermore,

there was a significant interaction between the effects of *Experiment* and *Competitor Type* on looking proportions, $F(1, 33184) = 167.01$, $p < 0.001$, $\eta^2 < 0.001$.

Post-hoc t-tests revealed that mean looking proportions to the *onset competitor* were significantly lower when allowing participants no pre-naming time (0.479) as compared to allowing them 1s pre-naming time (0.507), $t(16068) = 3.534$, $p < 0.001$, $d = 0.035$. Furthermore, mean looking proportions to the *rhyme* competitor were significantly lower when allowing participants no pre-naming time (0.484) as compared to allowing them 1s pre-naming time (0.596), $t(16010) = -14.784$, $p < 0.001$, $d = 0.072$. Bonferroni correction was applied to all t-tests.

5.4 Discussion

Results revealed that there was still a, reduced, *rhyme* effect observable when allowing no preview of the images before hearing the spoken target word. These results suggest that the presence of a *rhyme* effect in Experiment 3b does not mainly stem from the much longer pre-naming time of one second as compared to 200ms in Experiment 1. Instead, a *rhyme* effect seems to be observable with no pre-naming time at all supporting the idea that the presence of an *onset* competitor may have overshadowed subtle *rhyme* effects in Experiment 1. It remains unclear, however, whether the mere reduction of the visual scene to two images may have lead to a greater importance being placed on *rhyme* competi-

tors as compared to a much more complex visual scene containg four images as presented in Experiment 1.

Under the conditions of the present experiment, the overall *onset* effect vanished. These results are in contrast with results from Experiment 3b where adults were given one second to view the images before hearing the target word. Under these conditions, there was a very clear *onset* effect as well as *rhyme* effect. The differing results suggest that adults may be using different strategies of encoding spoken words and picture-word matching depending on how much information they are given of the visual display before hearing the spoken words. In particular, the present findings suggest that when given time to implicitly name images, listeners might be using a more incremental strategy of processing the auditory input whereby they place more emphasis on the first phoneme of a word. However, if they hear the spoken word without any prior information on the visual display, they may be using a more global continuous mapping strategy taking into account the overall similarity of two words rather than placing an increased importance on the first phoneme of a word.

This interpretation would also explain why Huettig & McQueen (2007) had problems detecting phonological effects in their setup when giving participants only 200ms to view the images before target word onset. Their task only concerned phonological *onset* competitors which are much harder to detect with a short pre-viewing phase as compared to *rhyme* competitors . It is possible that upon including *rhyme* com-

petitors in their experiments, Huettig & McQueen (2007) may have found phonological effects for these *rhyme* competitors even with a pre-viewing time as short as 200ms. Additionally, the use of line drawings may have slowed down participants' generating of the phonological code of the objects depicted which may have lead to a switch to more continuous mapping strategies and a focus on semantic and visual information rather than phonological one.

An alternative interpretation of the present results could be that adults may always make use of incremental strategies. However, if an images is presented after they have fully processed the spoken word, any information about the onset of the word may already be processed by this point and competition may have been discarded. In order to get a better understanding of incremental processing strategies, the present experiment could have synced the onset of the visual display with the onset of the target word rather than its offset.

More generally, it seems that adults rely less on phonological information and more on lexical, visual or semantic information when they are not given an opportunity to explore the visual display and potentially implicitly name the objects presented before hearing the spoken words. However, when presented with the opportunity to extract the phonological code of objects before hearing the target word, they seem to place much more importance on the initial phonological information presented by the spoken word and attribute less value to alternative information such as lexical, semantic or visual input.

Finally, it seems that *rhyme* effects can only be detected when they are not paired with *onset* competitors in the same visual display. This further supports the previous hypothesis that *rhyme* effects found by Allopenna et al. (1998) might mainly be due to trials on which the two types of competitors were separated. Overall, these findings underline the importance of the beginning of words in spoken-word recognition. Even though *rhymes* have a much larger overlap with the spoken word than *onset* competitors which only share the first phoneme with the spoken word, effects for the latter seem to be larger due to human processing mechanisms attributing greater importance to the beginning of a spoken word.

Chapter 6

Experiment 5: Replication Study

6.1 Introduction

So far, Experiments 1 and 3 have indicated that 2-year old infants do not preferentially look at *phonologically* related competitors as compared to *unrelated* distractors when investigating spoken-word recognition using a Visual World Paradigm. Experiment 3 showed that our initial suggestion that phonological effects in infants can only be revealed when *rhyme* and *onset* competitors are not presented in competition with each other could not be confirmed. Infants did not prefer looking at competitors *phonologically* related to the target word even when they were given 2 seconds to preview the pictures before hearing

the auditory word and when *rhyme* and *onset* competitors only ever appeared in separate trials.

However, there are some studies that do suggest a preference in infants for these types of *phonologically* related competitors. For instance, Swingley et al. (1999) were one of the first to demonstrate that 2-year olds take longer looking at target objects when they are paired with an *onset* competitor as compared to an *unrelated* distractor. Similar to our current results, they did not find any such effect when pairing the target object with a *rhyme* competitor. We would therefore have expected to demonstrate *onset* but not *rhyme* effects in our own setup.

Furthermore, Mani & Plunkett (2011) have successfully used priming paradigms to demonstrate that by the age of 24 months, infants' lexicons seem to be structured according to phonological similarity allowing phonologically related words to become activated and compete during word recognition. More recently, Chow et al. (2017) used a visual world paradigm to demonstrate 2-year-olds' increased looking proportions towards *onset* competitors as compared to unrelated distractors shortly after target word onset.

Finally, an experiment previously conducted in the Oxford BabyLab (Chow et al., 2015) using a visual world paradigm with 2-year-olds showed convincing *onset* as well as *rhyme* effects. The differences between this study and the experiments conducted for this thesis so far are the much longer pre-naming phase and larger phonological overlap between target words and *phonological* competitors in the former.

While the previous unpublished study used a pre-naming phase of 6 seconds, experiments undertaken for this thesis used much shorter pre-naming times of 200-2000ms. Furthermore, in the recent unpublished study, 5 out of 8 *onset* competitors not only shared their initial consonant with the spoken word but also their vowel. The remaining three *onset* competitors had vowels very similar to the spoken word matching it at least in terms of vowel height. In contrast, experiments conducted for this thesis so far exclusively utilised *onset* stimuli that only matched the spoken word in terms of its first consonant. It is possible that the much longer pre-naming time in the previous unpublished study enabled infants to implicitly name all images in the visual display before hearing the target word facilitating phonological effects. Similarly, the larger overlap between spoken word and *onset* competitors in this study may have contributed to more prominent *onset* effects. Finally, experiments of this thesis so far used stimulus repetition whereby objects that acted as *onset* competitor in one trial would appear as *rhyme* competitors or *unrelated* distractors on following trials. The experiment previously conducted at the Oxford BabyLab (Chow et al., 2015) did not make use of stimulus repetitions but instead presented entirely new objects to infants on each trial. It is possible that the stimulus repetition used throughout this thesis may have activated processes in infants that may have overshadowed any effects of phonological processing. However, it is also possible that the effects found in the previous study were simply due to chance and may not be replicable.

In order to investigate these possibilities, the aim of the present experiment was to replicate the findings previously made in the Oxford BabyLab using the same stimuli as well as timings as previously employed.

6.2 Methods

6.2.1 Participants

24 infants aged between 29.47 and 30.59 months (M = 30.01, SD = 0.31, Female: 11, Male: 13) recruited from monolingual British households were included in the analysis of this study. Recruitment was conducted in the same manner as in Experiment 1. An additional 2 infants were excluded from analysis due to being fussy.

6.2.2 Design

The design of this experiment was very similar to Experiment 1. Eye movement behaviour was recorded in a visual world paradigm displaying four pictures. The experiment contained two types of trials: **target absent** trials which served as experimental trials and **target present** trials which were used as filler trials. On **target absent** trials, the target object was not present among the four pictures shown on the screen. However, two phonologically related objects were displayed: one *onset* competitor which shared its onset with the auditory target word

(i.e. *cat - carrot*) and one *rhyme* competitor which rhymed with the target word (i.e. *cat - hat*). The two remaining *unrelated* distractors were neither phonologically nor visually or semantically related to the target word. On **target present** trials, the named object was among the four pictures displayed; together with three distractor objects that were phonologically, visually and semantically unrelated to the target object. **Target present** trials served to prevent infants from getting frustrated by the absence of target objects. In total, there were 8 experimental trials and 6 filler trials. Eye movements were recorded using a Tobii TX300 automated eye-tracker. Looking proportions per time-bin to *onset* competitors, *rhyme* competitors and *unrelated* distractors served as the dependent variable.

6.2.3 Stimuli

Infants were presented with one of four pseudo-randomised lists (see table C.1, table C.2, table C.3, table C.4). Each list started with 3 **target present** trials and was followed by a sequence that alternated between two **target absent** trials followed by one **target present** trial. Every object only appeared once within this experiment. One crucial difference to Experiment 1 was that the majority of *onset* competitors (5 out of 8) not only shared their initial consonant with the spoken word but also their vowel. While the remaining three *onset* competitors (*pear - pen, bag - ball, wall - watch*) did not have an identical vowel to the spoken word, their vowels were very similar and were at least matched

in terms of vowel height. For a detailed description of stimuli selection, see Experiment 4 in Chow et al. (2015).

6.2.4 Procedure

For each trial, participants first saw an attention getter in the middle of the screen. The attention getter comprised of a rotating object lasting 1s and was accompanied by a sparkling sound. A four picture display appeared 500ms after the offset of the attention getter and stayed on the screen for 10 seconds. The visual display was accompanied by an auditory sentence which instructed infants to look at the target object (e.g. "Look at the cat"). The onset of the target word appeared 6 seconds after the onset of the visual display. There was therefore a 6s pre-naming phase and a 4s post-naming phase (see fig. 6.1). It was anticipated that the long pre-naming phase might allow infants to implicitly name all objects before hearing the target word which might facilitate the detection of phonological relationships between visual objects and the spoken word.

6.2.5 Analysis

12 trials (6.25%) were excluded from analysis because they contained more than 75% track loss. Looking proportions were calculated and statistical analyses carried out in the same way as in Experiment 1.

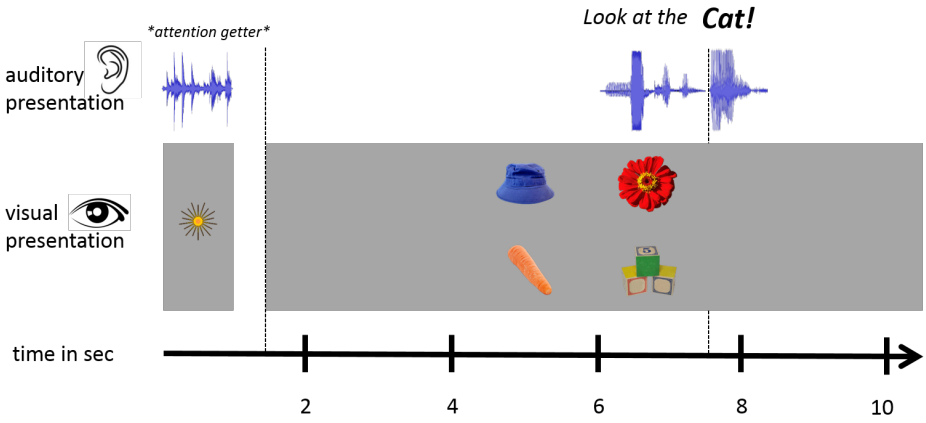


Figure 6.1: Example Trial

6.3 Results

Figure 6.2 displays the time course of looking proportions to the four pictures averaged across all participants and trials. The plot indicates potential preferential looking towards the *onset* competitor starting approximately 700ms after target word onset and lasting roughly one second. The raw data does not suggest a preference for the *rhyme* competitor over unrelated distractors at any time point.

6.3.1 Growth Curve Analysis

The overall time course of looking proportions between 600-3000ms after the onset of the target word was modelled with fourth-order orthogonal polynomials and fixed effect of *competitor type* on all time terms. The window of analysis was identical to the original experiment by Chow et al. (2015) in order to increase comparability. Unrelated distractors were combined and treated as the baseline and parameters

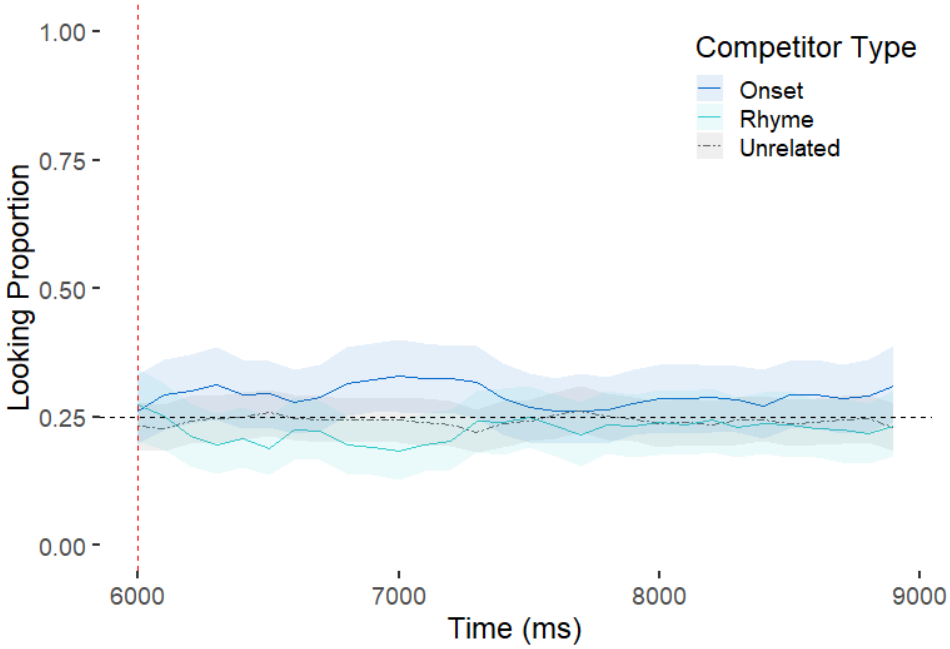


Figure 6.2: Overall Looking Proportions. The dotted red line marks the onset of the auditory word and the dotted horizontal line represents looking proportions at chance level of 0.25.

were estimated for *onset* and *rhyme* competitors. The model also included random effects of participants on all time terms and random effects of auditory stimulus nested under participant random effects on all time terms.

Figure 6.3 shows the model between 600 and 3000ms after target word onset. The figure suggests early increased looking proportions to the *onset* competitor starting shortly after target word onset and lasting approximately 1000ms. The results of the statistical model are summarised in Table 6.1. Neither the intercept nor the linear, quadratic, cubic or quartic terms were significant for either the *onset* or the *rhyme* competitor suggesting that looking proportions to

phonologically related competitors did not differ in magnitude and trajectory from looking proportions to the *unrelated* distractors.

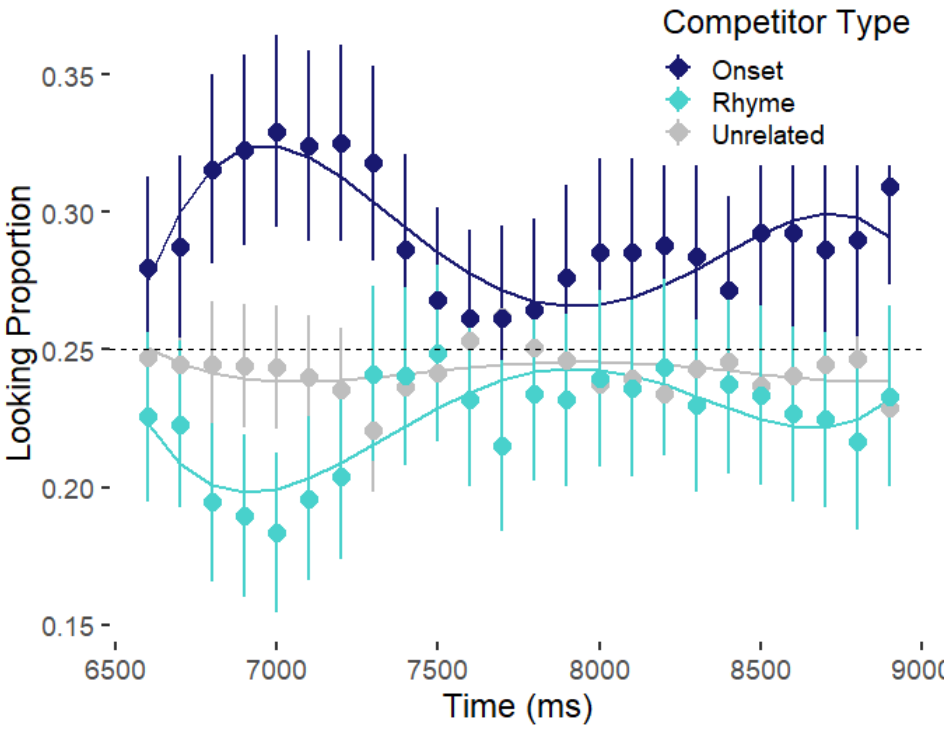


Figure 6.3: Growth curve analysis for infant data. Points represent data and lines display the model.

Fixed Effects	Model Terms	Est. (SE)	*t*	*p*
Onset	Intercept	-291.13(171.51)	-1.70	0.090
	Linear	3411.23(2016.42)	1.69	0.091
	Quadratic	-2157.70(1287.83)	-1.68	0.094
	Cubic	781.52(475.32)	1.64	0.100
	Quartic	-129.05(81.54)	-1.58	0.114
Rhyme	Intercept	157.88(181.78)	0.87	0.385
	Linear	-1857.65(2136.97)	-0.87	0.385
	Quadratic	1185.77(1364.56)	0.87	0.385
	Cubic	-435.57(503.45)	-0.87	0.387
	Quartic	73.54(86.32)	0.85	0.394
		***p<.001, **p<.01, *p<.05		

Table 6.1: Results of infant model with fixed effects of competitor type.

6.3.2 Individual Trial Analysis

Since the graph seems to suggest increased looking proportions towards *onset* competitors but the model did not produce any significant results, individual trials were inspected for this experiment. Figure 6.4 displays the time course of looking proportions separated for each trial. It seems as if the trend for an *onset* effect observed in the overall plot mainly stems from one particular trial, namely trial 2 (LBeans). In this trial, the spoken sentence was *"Look at the **beans**."* and the picture for the *onset* competitor was a **bee**.

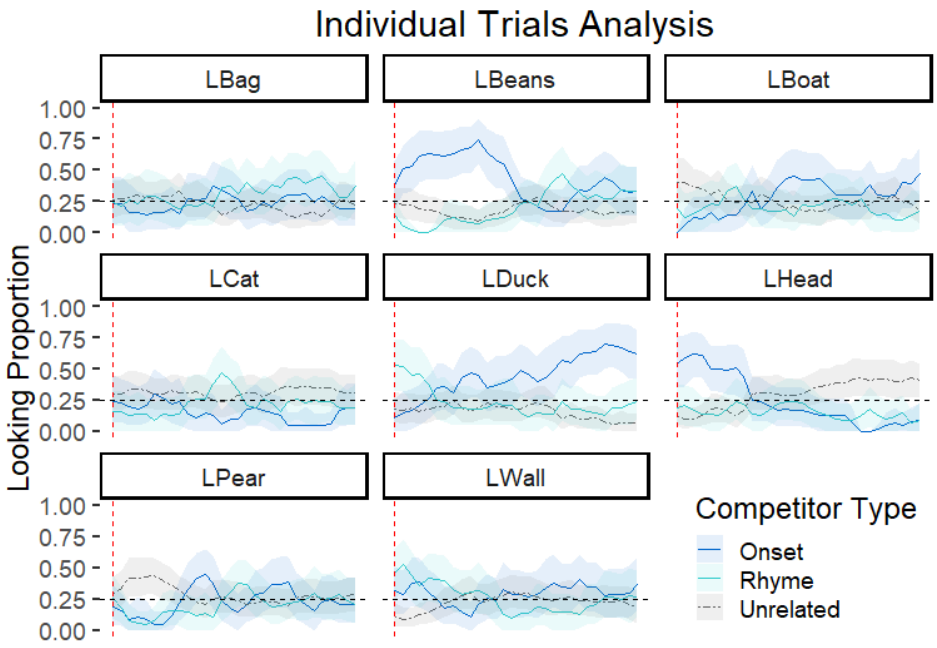


Figure 6.4: Overall Looking Proportions separated by trial. The dotted red line marks the onset of the auditory word and the dotted horizontal line represents looking proportions at chance level of 0.25.

In order to investigate whether the *Beans* trial is in fact the sole contributor to the *onset* effect observed, Figure 6.5 displays the time course of looking proportions for all trials excluding the *Beans* trial. The figure indicates that the *onset* effect disappears when removing the *Beans* trial, confirming that this particular trial is in fact responsible for the *onset* effect observed in the overall data.

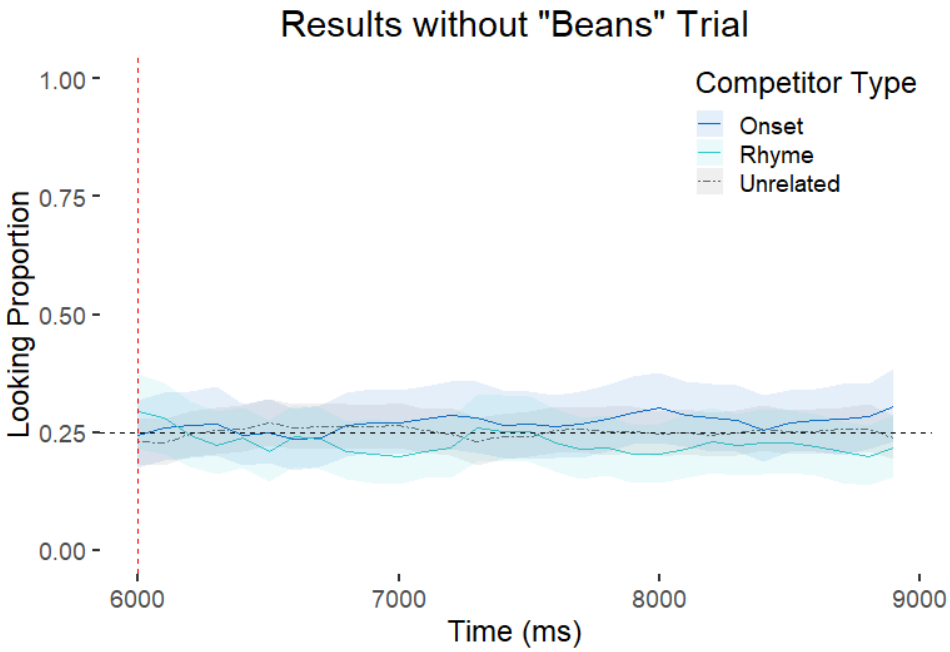


Figure 6.5: Overall Looking Proportions excluding the *Beans* trial. The dotted red line marks the onset of the auditory word and the dotted horizontal line represents looking proportions at chance level of 0.25.

Growth Curve Analysis without "Beans" Trial

For the second model, the overall time course of looking proportions between 600-3000ms after target word onset was modelled with fourth-order orthogonal polynomials and fixed effect of *competitor type* on all time terms for data excluding the *Beans* trial. Unrelated distractors were combined and treated as the baseline and parameters were estimated for *onset* and *rhyme* competitors. The model also included random effects of participants on all time terms and random effects of auditory stimulus nested under participant random effects on all time terms.

Figure 6.6 shows the model between 600 and 3000ms after onset of the visual display. The figure suggests that error bars for both types of phonological competitors overlap with error bars for the *unrelated* distractors. The results of the statistical model are summarised in Table 6.1. Neither the intercept nor the linear, quadratic, cubic or quartic terms were significant for either the *onset* or the *rhyme* competitor suggesting that looking proportions to phonologically related competitors did not differ in magnitude and trajectory from looking proportions to the *unrelated* distractors.

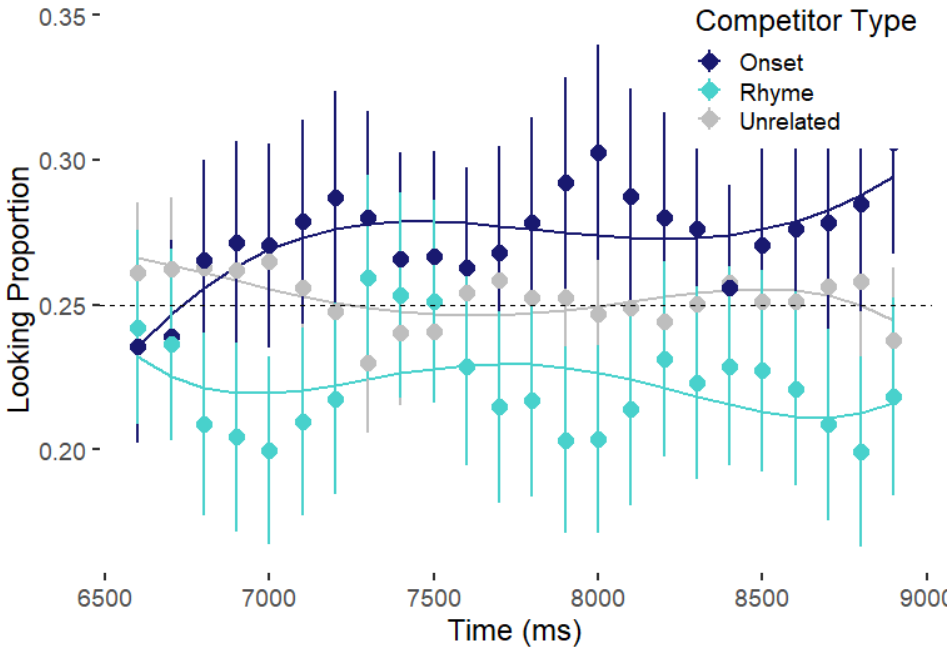


Figure 6.6: Growth curve analysis for infant data excluding *Beans* trial. Points represent data and lines display the model.

Fixed Effects	Model Terms	Est. (SE)	*t*	*p*
Onset	Intercept	6.77(185.44)	0.04	0.971
	Linear	102.11(2179.92)	-0.05	0.963
	Quadratic	96.79(1391.89)	0.07	0.945
	Cubic	-53.97(513.50)	-0.11	0.916
	Quartic	13.90(88.03)	0.16	0.875
Rhyme	Intercept	125.27(193.37)	0.65	0.517
	Linear	-1482.68(2273.54)	-0.65	0.514
	Quadratic	957.16(1452.31)	0.66	0.510
	Cubic	-358.94(536.17)	-0.67	0.503
	Quartic	62.62(92.02)	0.68	0.496
		***p<.001, **p<.01, *p<.05		

Table 6.2: Results of infant model excluding *Beans* trial with fixed effects of competitor type.

6.3.3 Comparison with Original Study

Following the present findings, results by Chow et al. (2015) were re-analysed including a detailed analysis of individual trials as well as an analysis without the critical trial containing the words "beans" and "bee". Reanalysis revealed that the original results were very similar to the results found in the current experiment. Namely, the apparent *onset* effect was mainly driven by one critical trial and eliminating this trial from analysis lead to disappearance of the apparent *onset* effect. For an overview of the results from the original study, see Figure 6.7, and Figure 6.9.

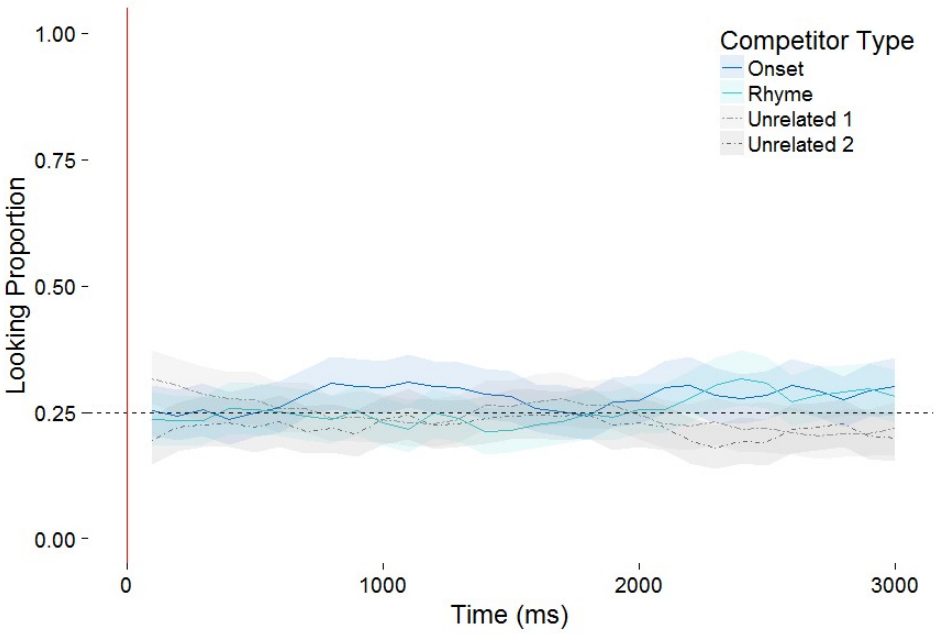


Figure 6.7: Overall Looking Proportions for the original study by Chow et al. (2015). The dotted red line marks the onset of the auditory word and the dotted horizontal line represents looking proportions at chance level of 0.25.

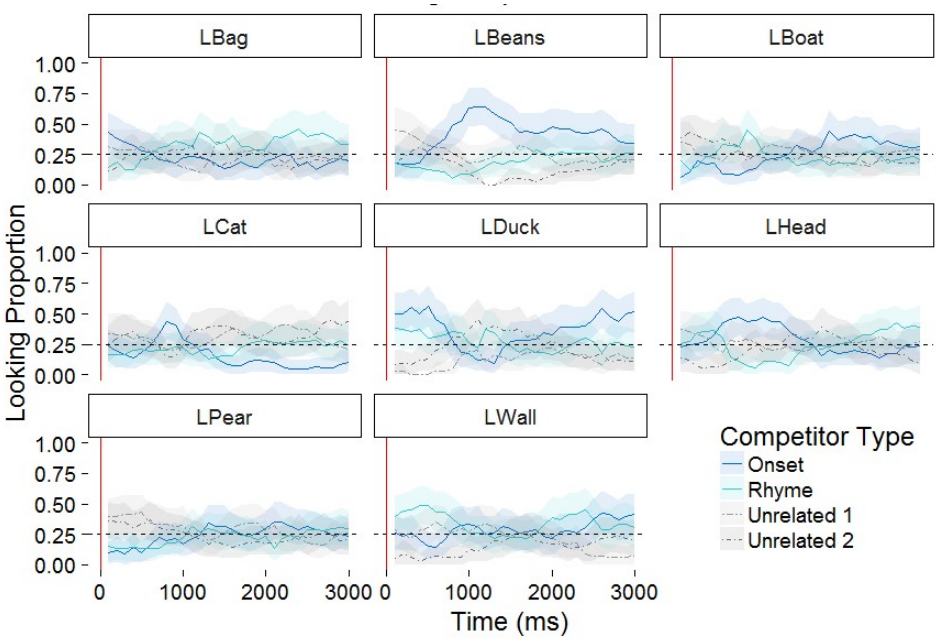


Figure 6.8: Overall Looking Proportions for the original study separated by trial.

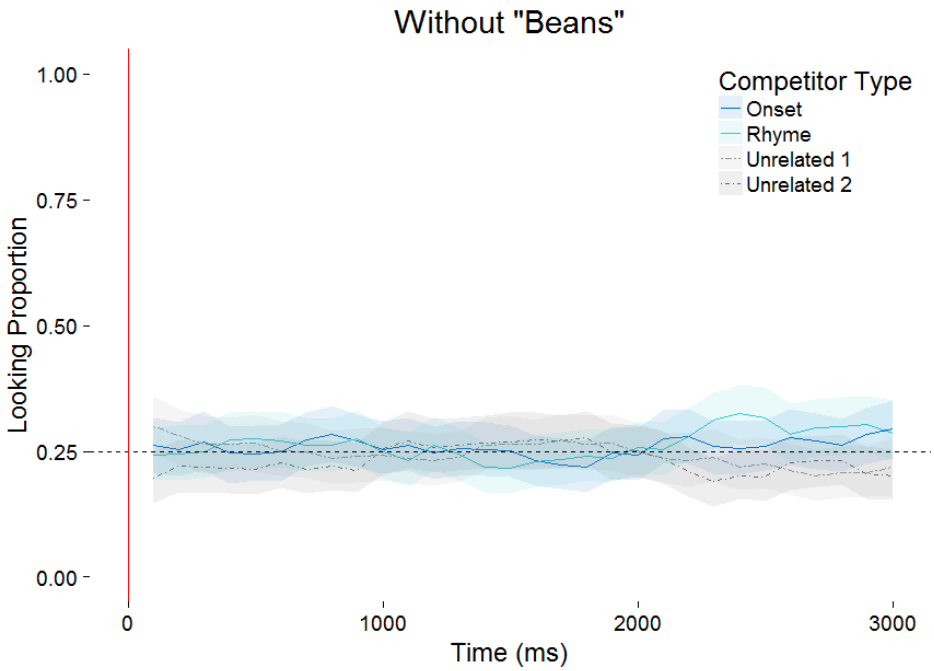


Figure 6.9: Overall Looking Proportions for the original study excluding the *Beans* trial. The dotted red line marks the onset of the auditory word and the dotted horizontal line represents looking proportions at chance level of 0.25.

6.4 Discussion

While visual inspection of the present results initially seemed to suggest that infants preferentially look at *onset* competitors over *rhyme* competitors and *unrelated* distractors when allowing them 6 seconds to preview the images before hearing the target word, statistical analysis did not reveal any significant effects. Overall, 2-year-olds' looking proportions towards phonological competitors do not seem to be higher than towards unrelated distractors even with a pre-viewing time of 6 seconds or when avoiding any stimulus repetition throughout the exper-

iment. Closer inspection of individual trials revealed that this apparent *onset* effect was driven by only one particular trial. In the trial responsible for the apparent *onset* effect, infants saw four pictures - one of them displaying a **bee** - and heard the sentence *"Look at the **beans**."*.

In line with Experiments 1 and 3a, the present findings suggest that phonological factors do not seem to modulate infants' attention during spoken-word recognition at 2 years of age. This would suggest that, unlike adults, 2-year-olds do neither make use of incremental nor continuous strategies of processing spoken words. It is possible that factors such as semantic or visual similarity play a greater role in guiding infants' attention at this age. Such strategies might help them in learning new words by preventing them from excluding possible lexical candidates solely based on phonological information (Walley, 1993). However, it is also possible that the very low number of experimental trials used in the present experiments might not have been a sensitive enough measure in order to pick up the relatively small phonological effects in infants.

There are two possible explanations for why one particular trial has so far been the only trial to elicit an *onset* effect in infants.

6.4.1 Word Embedment

One reason could be that the word **bee** is actually embedded within the word **beans**. Therefore, when infants hear the first consonant and vowel part of the word **beans**, they experience a complete match be-

tween auditory input and visual input from one of the images, namely, the object **bee**. Once they experience this complete match between auditory and visual input, they may decide that **bee** is in fact the target word and therefore fixate on this object in a similar way as they would in a target present trial. It is only when they hear the final consonants of the word **beans** that they realise that there is a mismatch between the auditory input and the object that they are currently looking at. This would explain why looking proportions to **bee** eventually decrease going back to near chance level. It may take infants a few hundreds of milliseconds to process the fact that spoken word and visual object do not match and to disengage from the object that they had previously looked at, which could explain why looking proportions to **bee** do not immediately go back to near chance level as soon as infants hear the remaining consonants of the word **beans**.

6.4.2 Perceived Mispronunciation

However, there is an alternative possible explanation for the time course observed in the *Beans* trial: infants might simply have misheard the word **beans** for **bee**. This is a very likely explanation since the consonant "n" in **beans** is not a very strong one and might have been overheard quite easily. In this scenario, infants would have in fact believed that they were looking at the correct object when fixating the **bee**. The fact that looking proportions towards **bee** decrease after approximately 1.5 seconds could be explained with infants becoming dis-

interested in the object they are currently looking at and deciding to explore again the entire range of pictures shown in the visual display. This is a plausible explanation since analysis of our **target present** trials shows that infants disengage from target objects some time after they have successfully fixated them. Unlike adults, infants do not continue fixating target objects until the end of a trial but instead go back to exploring the entire visual scene for further interesting information.

6.4.3 Impact of Individual Stimuli

The findings that one individual trial can have a large impact on overall experimental results also have important implications for the generalisability of the present findings as well as the setup of future studies. Such findings serve as an important reminder that by restricting experiments to a small subset of stimuli, it may become difficult to generalise findings from such setups to a broader understanding of spoken-word recognition. Furthermore, these observations emphasise the importance of having a well-balanced stimulus set and to take individual trial effects into account when conducting statistical analysis. Researcher should therefore make use of statistical methods such as Growth Curve Analysis (GCA) which account for variance of behaviour for different trials or stimuli (Mirman et al., 2008). In the present experiment, no statistically significant *onset* effects could be found despite initial visible inspection suggesting a large *onset* effect since GCA took into account possible outlier behaviour from individual trials. Other measures such

as simply taking mean looking proportions over time may not have been able to deliver such fine-grained results.

6.4.4 Conclusions

Taken together, the present results confirm findings in Experiments 1 and 3 that infants do not normally show a preference for *phonologically* related competitors over *unrelated* distractors during spoken-word recognition in a Visual World Paradigm. It appears that neither manipulating the amount of time given to inspect the images before target word onset (Experiment 1: 200ms, Experiment 3: 2s, Experiment 5: 6s), nor whether *onset* and *rhyme* are presented in direct competition with each other (Experiments 1 and 5) or separately (Experiment 3), nor whether the *onset* competitor overlaps with the spoken word only in its first consonant (Experiments 1 and 3) or in its first consonant as well as its vowel (Experiment 5) could reveal a preference in infants to fixate more on *phonologically* related competitors than *unrelated* distractors. The only scenario under which we were able to demonstrate a preference of an *onset* competitor was when its label was embedded within the spoken target word. However, it remains unclear whether this was due to infants simply needing more phonological overlap between target word and *onset* competitor or whether they may have in fact misheard the target word. Finally, it should be considered that the lack of statistically significant findings may also stem from a lack of

power due to the relatively low number of trials used for the present infant experiments.

Chapter 7

Experiment 6: Pseudowords

7.1 Introduction

Experiments 1, 3 and 5 demonstrated no preference for phonologically related competitors over unrelated distractors in 2-year-old infants when using a visual world paradigm with real words. It is possible that using real words engages the lexicon in a way that overwrites any phonological effects. As soon as infants notice that the named object is not among the objects displayed on the screen, they may revert to a behaviour of looking back and forth between pictures in the same manner as they would if the speech input did not provide them with any valuable information (Swingley & Fernald, 2002).

One way to investigate whether infants as young as 2 years can be sensitive to phonological similarities during spoken-word recognition, could be to replace the real words with pseudowords in order to avoid

lexical information overwriting possible phonological effects. Not only do pseudowords prevent interference of lexical information with phonological processing, they also allow us to control more carefully for the stimuli infants are presented with. Since the infant lexicon is not fully developed at 2 years of age, using monosyllabic real words of objects that are picturable poses quite a big constraint on the words that can be used with such infants. Additionally, the experiments contributing to this thesis aim to investigate possible *rhyme* effects, however, there is only a very limited amount of words available that rhyme with each other, are understood by a two year old, are monosyllabic and picturable. Such constraints mean that it becomes significantly harder to control for effects such as animacy or general likeability of an object when conducting visual world paradigms with infants. It is likely that such confounding effects have distorted our results in the previous experiments. The aim of the present experiment is therefore to determine whether phonological effects may be detected in 2-year-old infants when using pseudowords rather than real words.

In Experiments 3 and 4, it was established that adults are more likely to fixate *rhyme* competitors in a target absent design when they do not directly compete with *onset* competitors. This might be due to the relatively strong attention drawn towards *onset* competitors, thus overshadowing any increased attention that may have been drawn towards *rhyme* competitors. The present experiment will therefore include trials in which *rhyme* competitors directly compete with *onset* competitors

as well as trials in which the *rhyme* competitor is presented together only with *unrelated* distractors.

Finally, we learned from adult experiments (see Experiment 3) that looking proportions to *rhyme* competitors are especially increased when the first phoneme of the spoken word is phonologically very similar to the first phoneme of the *rhyme* competitor. Specifically, Experiment 3 compared conditions in which the first phonemes only differed in terms of voicing or differed in as many phonological features as possible. In order to determine whether infants' preference for rhyming pseudowords is similarly influenced by the amount of phonological similarity between the first phoneme of the spoken pseudoword and the corresponding rhyming object, the present experiment will also compare a *voice* condition and a *total mismatch* condition in which the two phonemes differ in terms of voice, place and manner. If infants show earlier and stronger preference for rhymes which are phonologically very similar to the spoken word as compared to dissimilar ones, this would indicate that at the age of 2 years lexical representations are already fine-grained enough to distinguish sub-phonemic details. First evidence for such fine-grained representations comes from studies by White & Morgan (2008) and Tamasi et al. (2019) who found differing looking behaviour for mispronunciations of varying degrees.

If we succeed in eliciting phonological effects in infants using pseudowords, then this setup would allow us to explore whether these effects are, like in adults, determined by whether the *rhyme* competes

with the onset and the amount of phonological similarity between the pseudoword and the rhyming object.

7.2 Methods

7.2.1 Participants

Data from 31 infants aged 30 months ($M = 30.23$, $SD = 0.29$, Female: 21, Male: 10) recruited from monolingual British households were included in the analysis of this study. Recruitment was conducted in the same manner as in Experiment 1. Three additional infants were excluded from analysis due to being fussy (1) or problems with calibration (2).

7.2.2 Design

The design of this experiment was very similar to Experiment 1. Eye movement behaviour was recorded in a visual world paradigm displaying four pictures. The experiment contained two types of trials: **pseudoword** trials which served as experimental trials and **target present** trials which were used as filler trials. On **pseudoword** trials, the spoken word was a monosyllabic non-word and among the displayed object was one object that shared the same vowel as well as final phoneme as the non-word (e.g. *pall* - *ball*). The **pseudoword** trials themselves consisted of three different conditions: a *rhyme close* condition in which

the first phoneme of the spoken pseudoword and the *rhyming* object only differed in terms of voicing (e.g. *pook* - *book*), a *rhyme distant* condition in which they differed in terms of place, manner and voicing (e.g. *koon* - *moon*); and an *onset* condition which was identical to the *rhyme close* condition, however, one of the remaining three distractors had a first phoneme identical to the first phoneme of the spoken non-word (e.g. *pus* - *pear* + *bus*). Any *unrelated* distractors were neither phonologically nor visually or semantically related to the target word. **Target present** trials served to prevent infants from getting frustrated by the absence of target objects. In total, there were 24 experimental trials and 14 filler trials. Eye movements were recorded using a Tobii TX300 automated eye-tracker. Looking proportions per time bin to *rhyme* competitors, *onset* competitors and *unrelated* distractors served as the dependent variable.

7.2.3 Stimuli

A list of stimuli was created by extracting all monosyllabic words from the Oxford Communicative Development Inventories (CDI, Hamilton et al. (2000)). Only words that were imageable were further considered. For **target absent** experimental trials, all animate objects were excluded from the list. For the remaining non-animate, imageable, monosyllabic words which are normally understood by infants at the age of 2 years, pseudowords were created which either differed from the original word only differed in terms of voicing or in terms of place, manner

and voicing (see above). Remaining imageable, monosyllabic as well as animate words were used to create **target absent** trials.

Infants were presented with one of four pseudo-randomised lists (see Appendix D.1, D.2, D.3, D.4). Each list started with 3 **target present** trials and was followed by a sequence that alternated between two **pseudoword** trials followed by one **target present** trial. Every object only appeared once within this experiment.

7.2.4 Procedure

For each trial, infants first saw an attention getter in the middle of the screen. The attention getter comprised of a rotating object lasting 1s and was accompanied by a sparkling sound. It was followed by an auditory sentence which instructed infants to look at an object (e.g. "Look Poat!"). A four picture display appeared immediately at the offset of the spoken sentence and stayed on the screen for 3 seconds (see Figure 7.1). No pre-naming phase was chosen for this experiment in order to facilitate interpretation of results. Presenting the entire spoken word before the onset of the visual display avoids any possibility of pre-naming taking place and therefore ensures that infants match the newly processed visual input to the spoken words rather than simultaneously encoding visual and auditory input.

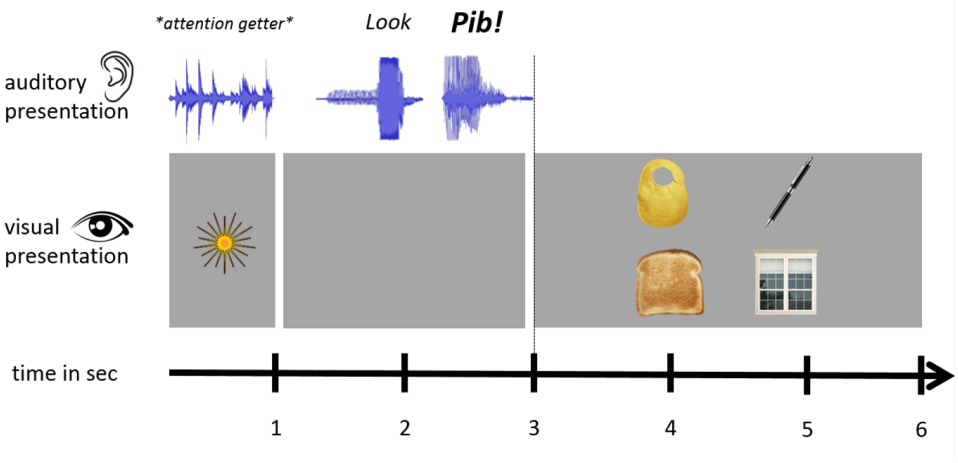


Figure 7.1: Example Trial

7.2.5 Analysis

55 trials (7.48%) were excluded from analysis because they contained more than 75% track loss. Looking proportions were calculated and statistical analyses carried out in the same way as in Experiment 1.

7.3 Results

Figure 7.2 displays the time course of looking proportions to the four pictures averaged across all participants and trials. Looking proportions towards the *rhyme* competitor were collated for the *rhyme close*, *rhyme distant* and the *onset* conditions. Looking proportions towards the *onset* competitor were derived from trials of the *onset* condition. The plot indicates potential preferential looking towards the *rhyme* competitor starting approximately 700ms after target word offset and lasting for the remainder of the trial. The raw data

further suggests a small early preference for the *onset* competitor over *unrelated* distractors starting from target word offset and lasting approximately 600ms.

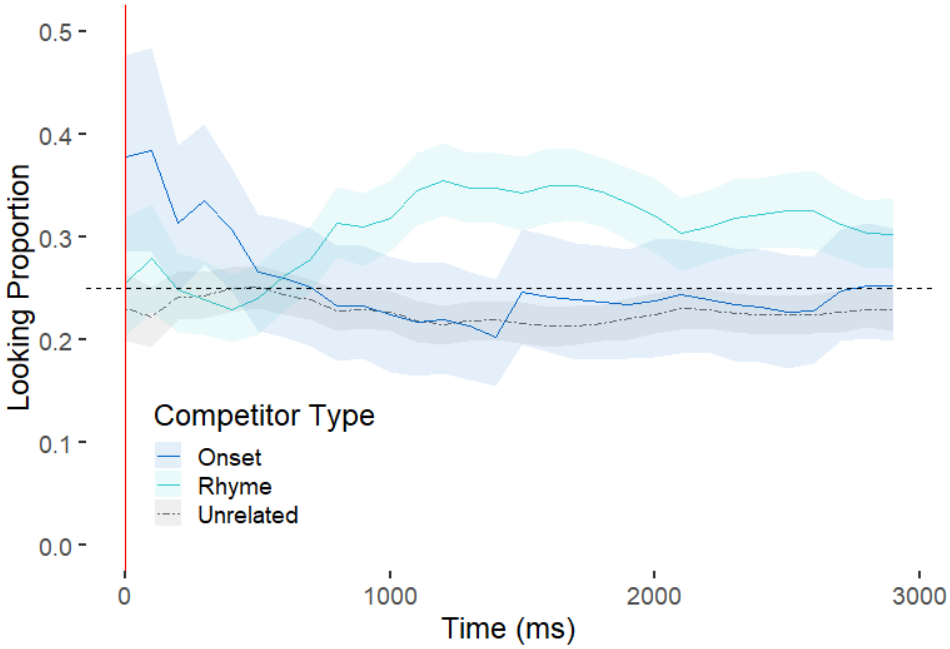


Figure 7.2: Overall Looking Proportions. The red line marks the offset of the auditory word which occurred simultaneously with the onset of the visual display. The dotted horizontal line represents looking proportions at chance level of 0.25.

7.3.1 Growth Curve Analysis

The overall time course of looking proportions between 0-3000ms after the offset of the target word was modelled with third-order orthogonal polynomials and fixed effect of *competitor type* on all time terms. Unrelated distractors were combined and treated as the baseline and param-

eters were estimated for *onset* and *rhyme* competitors. The model also included random effects of participants on all time terms and random effects of auditory stimulus nested under participant random effects on all time terms.

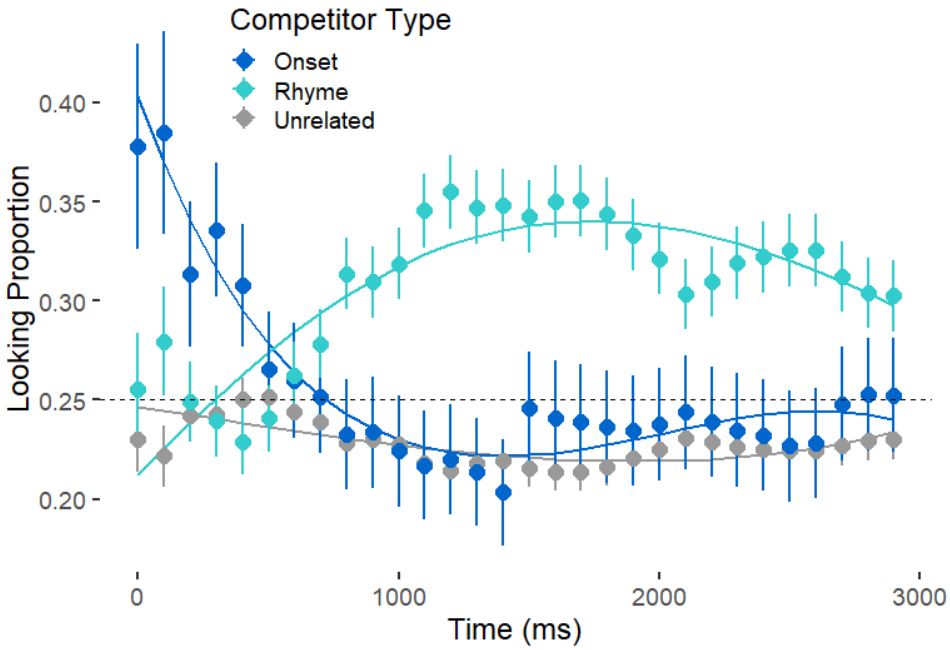


Figure 7.3: Growth curve analysis for first model with fixed effects of competitor type for a time window of 0-3000ms after onset of the visual display. Points represent data and lines display the model.

Figure 7.3 shows the model between 0 and 3000ms after target word offset. This time window was chosen based on visual inspection suggesting that looking proportions towards the *onset* competitor start increasing immediately at target word offset. The figure suggests early increased looking proportions to the *onset* competitor starting immediately with target word offset and lasting approximately 600ms. It further suggests increased looking proportions towards the *rhyme*

competitor starting approximately 500ms after target word offset and lasting for the remainder of the trial. The results of the statistical model are summarised in Table 7.1. The intercept terms were significant for *onset* as well as *rhyme* competitors suggesting that looking proportions to both types of phonologically related competitors were higher than for *unrelated* distractors. There were significant linear and quadratic terms for *onset* and *rhyme* competitors as well as significant cubic terms for the *onset* competitor suggesting that the trajectory of looking proportions differed significantly between both types of phonological competitors and the *unrelated* distractors.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Onset	Intercept	0.14(0.03)	4.37	<.001***
	Linear	-0.58(0.18)	-3.21	0.001**
	Quadratic	0.66(0.19)	3.56	<.001***
	Cubic	-0.42(0.18)	-2.34	0.019*
Rhyme	Intercept	0.40(0.02)	20.03	<.001***
	Linear	0.83(0.12)	6.89	<.001***
	Quadratic	-0.90(0.12)	-7.45	<.001***
	Cubic	0.02(0.12)	0.20	0.840
		***p<.001, **p<.01, *p<.05		

Table 7.1: Results of the first model with fixed effects of competitor type for a time window of 0-3000ms after onset of the visual display.

7.3.2 Baseline Inspection

The *onset* effect observed in the present experiment seems to be due to an immediate increase in looking proportions towards the *onset*

competitor at target word offset and onset of the visual display. Since such early fixations are uncommon in 2-year-olds, it is possible that increased looking proportions may stem from baseline differences before the onset of the visual display. Figure 7.4 displays looking proportions over the entire course of the trial including the phase in which no visual display was shown. It can be seen that looking proportions towards the location of the *onset* competitor were already increased before the onset of the visual display.

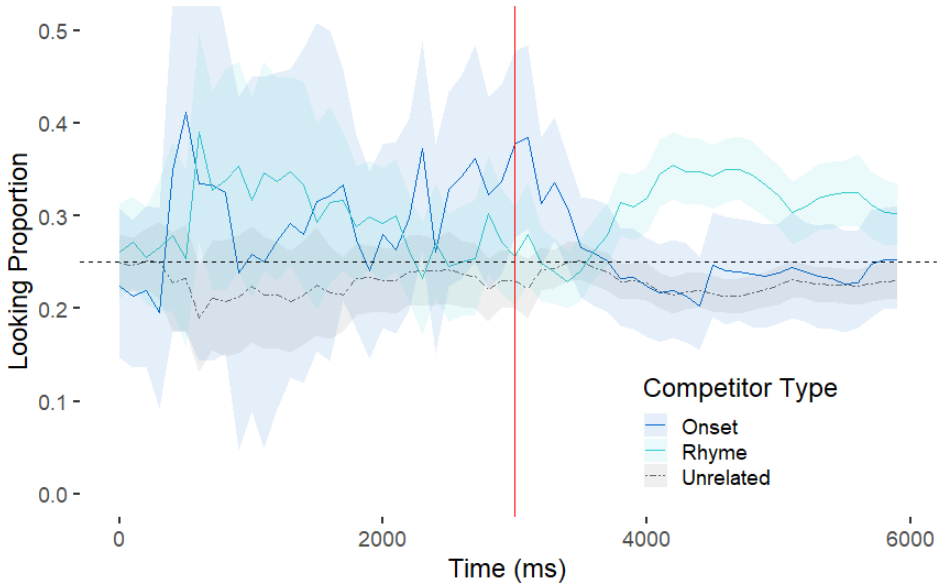


Figure 7.4: Overall Looking Proportions over the entire trial period. The red line marks the offset of the auditory word which occurred simultaneously with the onset of the visual display. The dotted horizontal line represents looking proportions at chance level of 0.25.

Given the observed baseline differences, growth curve analysis was repeated with a time window between 600-3000ms after the onset of the

visual display. This window of analysis is in line with Experiments 1 and 5 and takes into account findings that 2-year-olds typically start fixating on target objects approximately 680ms after target word onset (Fernald et al., 1998). All other parameters of the growth curve analysis were identical to the first model. Figure 7.5 shows the model between 600 and 3000ms after target word offset. The figure suggests increased looking proportions towards the *rhyme* competitor but no significant difference in looking proportions between the *onset* competitor and the *unrelated* distractor.

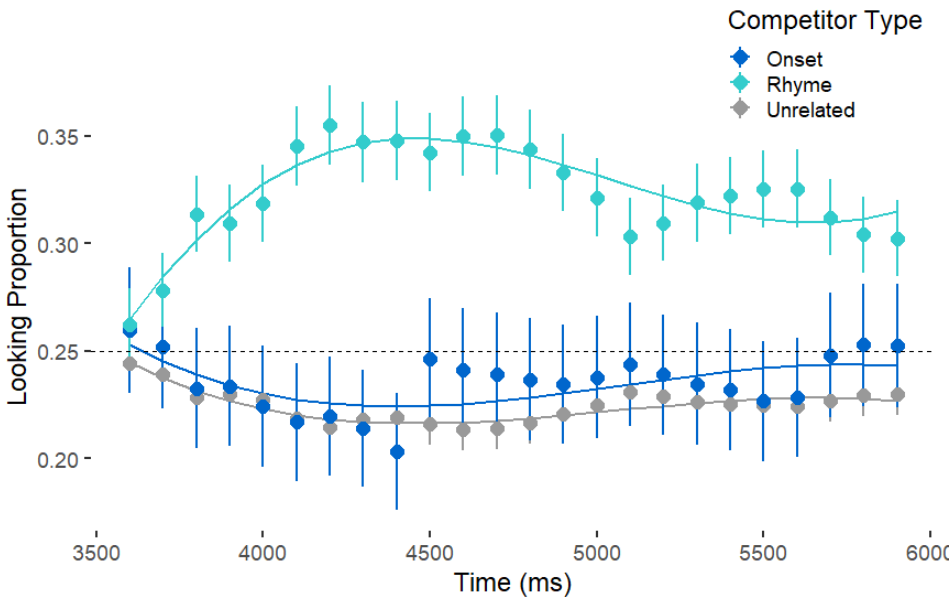


Figure 7.5: Growth curve analysis for second model with fixed effects of competitor type for a time window of 600-3000ms after onset of the visual display. Points represent data and lines display the model.

The results of the statistical model are summarised in Table 7.2. The intercept was significant for the *rhyme* competitor suggesting that looking proportions to the *rhyme* competitor was generally higher

than for the *onset* competitor and the *unrelated* distractors. There were significant linear, quadratic and cubic terms for the *rhyme* competitor suggesting that the trajectory of looking proportions differed significantly between the *rhyme* competitor and the *onset* competitor as well as the *unrelated* distractors. None of the intercept, linear, quadratic or cubic terms were significant for the *onset* competitor suggesting that looking proportions towards the *onset* competitor were not significantly different from looking proportions towards the *unrelated* distractors.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Onset	Intercept	0.19(2.73)	0.07	0.946
	Linear	-1.21(25.46)	-0.05	0.962
	Quadratic	0.83(14.85)	0.06	0.956
	Cubic	-0.18(4.15)	-0.04	0.966
Rhyme	Intercept	-6.94(1.67)	-4.15	<.001***
	Linear	67.944(15.55)	4.37	<.001***
	Quadratic	-37.72(9.06)	-4.16	<.001***
	Cubic	9.07(2.53)	3.59	<.001***
			***p<.001, **p<.01, *p<.05	

Table 7.2: Results of the second model with fixed effects of competitor type for a time window of 600-3000ms after onset of the visual display.

7.3.3 *Onset* Condition

For the third model, only trials from the *Onset* condition in which *rhyme* competitors were presented together with *onset* competitors

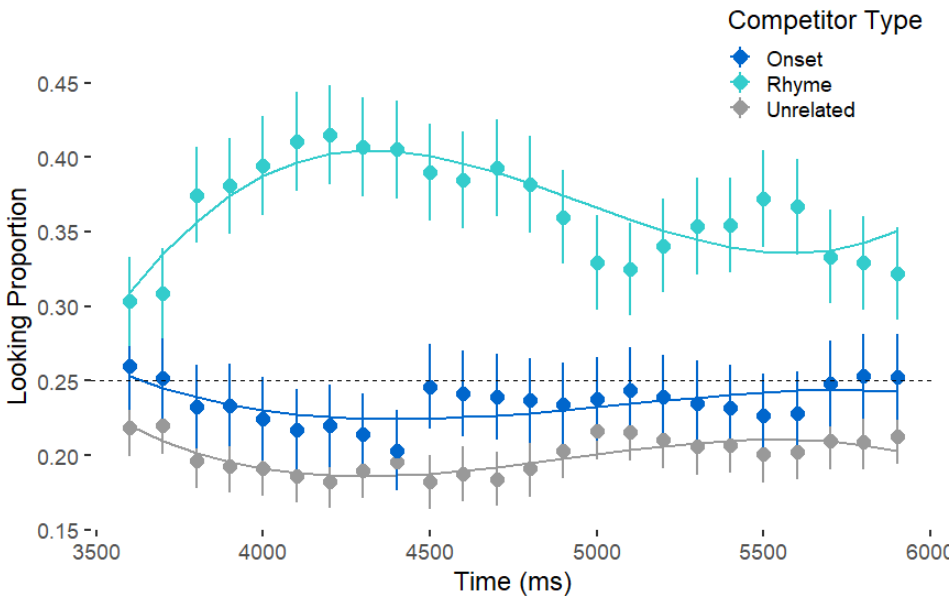


Figure 7.6: Growth curve analysis for third model with fixed effects of competitor type for the *Onset* condition using a time window of 600-3000ms after onset of the visual display. Points represent data and lines display the model.

and *unrelated* distractors were considered for analysis. The overall time course of looking proportions between 600-3000ms after the offset of the target word was modelled with third-order orthogonal polynomials and fixed effect of *competitor type* on all time terms. Unrelated distractors were combined and treated as the baseline and parameters were estimated for *onset* and *rhyme* competitors. The model also included random effects of participants on all time terms and random effects of auditory stimulus nested under participant random effects on all time terms. Figure 7.6 shows the model between 600 and 3000ms after target word offset. The figure suggests increased looking proportions towards the *rhyme* competitor but no significant difference in looking proportions between the *onset* competitor and the *unrelated* distractor.

The results of the statistical model are summarised in Table 7.3. The intercept was significant for the *rhyme* competitor suggesting that looking proportions to the *rhyme* competitor was generally higher than for the *onset* competitor and the *unrelated* distractors. There were significant linear, quadratic and cubic terms for the *rhyme* competitor suggesting that the trajectory of looking proportions differed significantly between the *rhyme* competitor and the *onset* competitor as well as the *unrelated* distractors. None of the intercept, linear, quadratic or cubic terms were significant for the *onset* competitor suggesting that looking proportions towards the *onset* competitor were not significantly different from looking proportions towards the *unrelated* distractors.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Onset	Intercept	-1.37(3.21)	-0.43	0.670
	Linear	14.77(29.89)	0.49	0.621
	Quadratic	-8.79(17.44)	-0.50	0.614
	Cubic	2.48(4.88)	0.51	0.612
Rhyme	Intercept	-10.08(3.00)	-3.36	<.001***
	Linear	100.77(27.90)	3.61	<.001***
	Quadratic	-57.77(16.27)	-3.55	<.001***
	Cubic	14.68(4.55)	3.23	0.001**
			***p<.001, **p<.01, *p<.05	

Table 7.3: Results of the third model with fixed effects of competitor type for the *Onset* condition using a time window of 600-3000ms after onset of the visual display.

7.3.4 *Rhyme Close* vs. *Rhyme Distant* Condition

For the fourth model, the overall time course of looking proportions between 600-3000ms after the offset of the target word was modelled with third-order orthogonal polynomials and fixed effect of *rhyme type* on all time terms. The *rhyme distant* condition was treated as the baseline and parameters were estimated for the *rhyme close* condition. The model also included random effects of participants on the intercept, linear and quadratic terms.

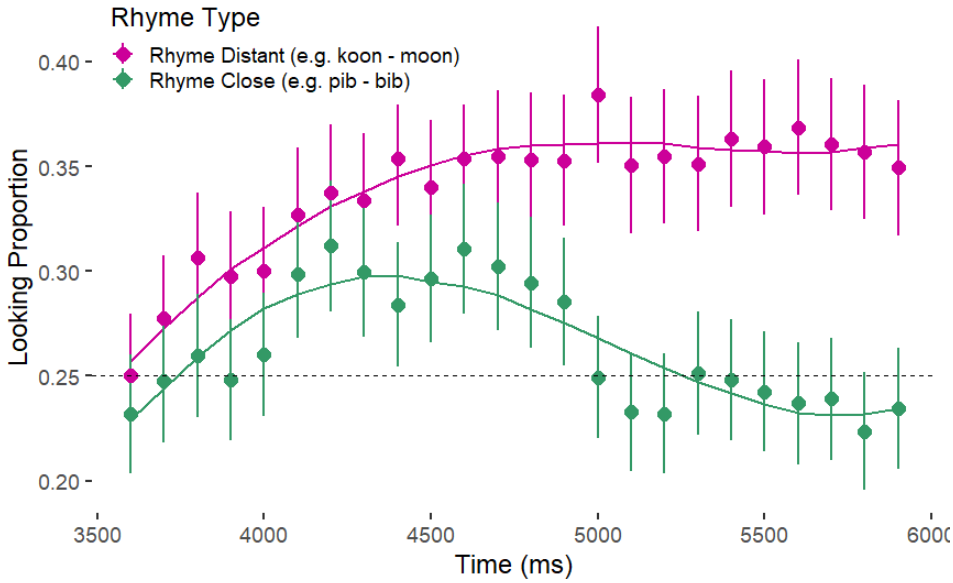


Figure 7.7: Growth curve analysis for the different rhyme types. Points represent data and lines display the model.

Figure 7.7 shows the fourth model between 600 and 3000ms after target word offset. The figure suggests increased looking proportions to both types of *rhyme* competitors starting approximately 700ms after

target word onset. Looking proportions towards the *rhyme* competitor were much higher and remained increased until the end of the trial for the *rhyme distant* condition while looking proportions in the *rhyme close* condition were generally lower and only lasted for approximately 1.5 seconds. The results of the statistical model are summarised in Table 7.4. None of the intercept, linear, quadratic or cubic terms were significant suggesting that looking proportions did not differ significantly between the *rhyme close* and the *rhyme distant* conditions.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Rhyme Close	Intercept	-2.54(3.53)	-0.72	0.472
	Linear	20.91(32.86)	0.64	0.525
	Quadratic	-14.02(19.13)	-0.73	0.463
	Cubic	3.69(5.34)	0.69	0.489
		***p<.001, **p<.01, *p<.05		

Table 7.4: Results of the fourth model with fixed effects of rhyme type.

7.3.5 Comparison with Target Looking

It is possible that looking proportions towards *rhyme* competitors were simply increased because infants in fact misheard the spoken pseudoword as the real phonological code of the visual *rhyme* competitor. If this was the case, their looking proportions towards the *rhyme* competitor should resemble looking proportions towards target objects in the **target present** filler trials. In order to investigate whether looking behaviour towards the mispronounced *rhyme* competitors indeed resembled looking behaviour towards target objects in the **target present**

filler trials, the overall time course of looking proportions between 0-3000ms after the offset of the target word was modelled with third-order orthogonal polynomials and fixed effect of *condition* on all time terms. The *target* object from **target present** trials (e.g. *cucumber* - *cucumber*) was treated as the baseline and parameters were estimated for the *rhyme* competitor in the *rhyme close* condition (e.g. *pook* - *book*) and the *rhyme distant* condition (e.g. *koon* - *moon*). The model also included random effects of participants on all time terms. Figure 7.8 shows the fifth model between 0 and 3000ms after target word offset. The figure suggests that looking proportions towards *target* objects increase much earlier and have a significantly larger amplitude than looking proportions towards either type of *rhyme* competitor.

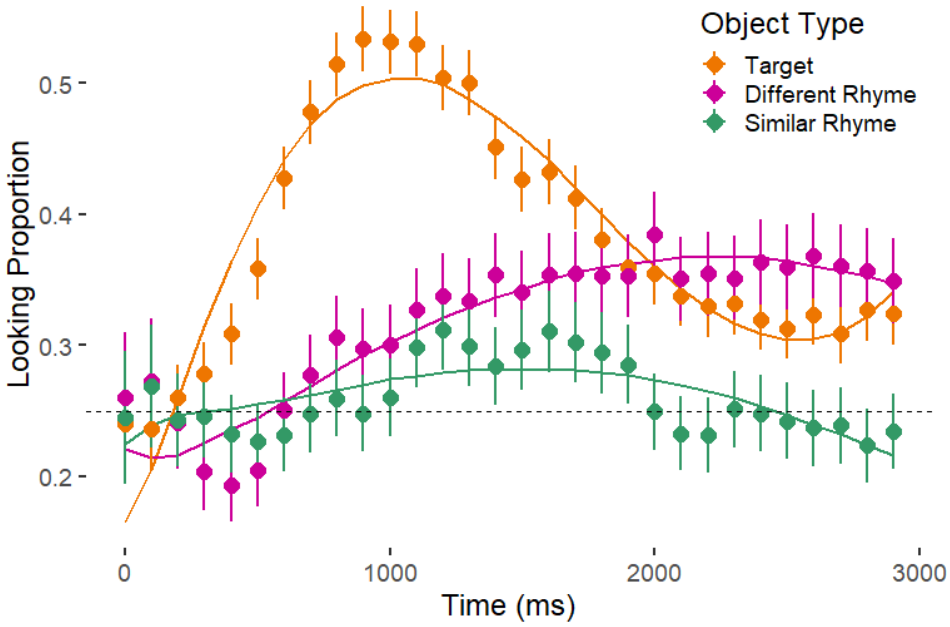


Figure 7.8: Growth curve analysis for targets versus rhyme competitors. Points represent data and lines display the model.

The results of the statistical model are summarised in Table 7.5. There were significant intercepts for both rhyme types suggesting that looking proportions towards *rhyme* competitors were generally lower than for *target* objects. Furthermore the linear, quadratic and cubic terms were significant for the *rhyme distant* condition and the quadratic and cubic terms were significant for the *rhyme close* condition suggesting that looking proportions towards both types of *rhyme* competitors followed a different pattern than towards *target* objects.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Rhyme Distant	Intercept	-0.29(0.04)	-8.19	<.001***
	Linear	1.44(0.22)	6.53	<.001***
	Quadratic	1.18(0.22)	5.37	<.001***
	Cubic	-1.43(0.21)	-6.81	<.001***
Rhyme Close	Intercept	-0.55(0.04)	-14.81	<.001***
	Linear	-0.11(0.22)	-0.47	0.635
	Quadratic	1.39(0.23)	6.16	<.001***
	Cubic	-1.53(0.22)	-7.03	<.001***
			***p<.001, **p<.01, *p<.05	

Table 7.5: Results of the fifth model with fixed effects of condition (*Target, Rhyme Distant, Rhyme Close)*.

7.4 Discussion

Results from this study revealed that when 2-year-old infants were presented with pseudowords, looking proportions towards *rhyme* competitors were increased as compared to *unrelated* distractors. Initial suggestions of an early *onset* effect could not be confirmed and seemed to

be due to baseline differences in looking proportions before the onset of the visual display. The present findings suggest that 2-year-olds do not simply seem to follow an incremental strategy when processing spoken words (e.g. as suggested by the Cohort model (Marslen-Wilson, 1987)) but their attention seems to rather be directed by the overall similarity between the words they hear and the phonological code of the objects they are presented with. One reason why the present experiment did not reveal any *onset* effects could be the lack of any previewing time of the images before infants heard the spoken words. Experiment 4 demonstrated that adults did not display any preference for *onset* competitors when the previewing time was completely removed. It is possible that allowing 2-year-olds some time to look at the images before hearing the target word might have lead to looking behaviour resembling simulations from continuous processing models such as TRACE (McClelland & Elman, 1986) with early increased looking proportions towards the *onset* competitor followed by later and longer lasting increase in looking proportions towards the *rhyme* competitor. More generally, these findings support the theory that by the age of two years, infants' lexicon seems to be structured according to phonological similarity allowing phonologically related words to become activated and compete for attention.

One may argue that the reason we found *rhyme* effects in 2-year-old infants with the present setup as opposed to previous experiments of this thesis could be because infants may simply have misheard the

pseudowords for the *rhyme* competitors. This would suggest that looking behaviour towards *rhyme* competitors in the **target absent** trials of this pseudoword study (e.g. *pook* - *book*) should resemble looking behaviour towards target objects in the **target present** filler trials (e.g. *cucumber* - *cucumber*). However, inspection of the target present filler trials revealed, that infants looked significantly less at the mispronounced *rhyme* competitors in the pseudoword trials than they looked at the target objects in the target present trials. Different processes, thus, seem to have taken place in the experimental target absent and the control target present trials rejecting the idea that the only reason the present experiment revealed *rhyme* effects in toddlers might be due to mishearing the pseudoword for the phonological code of the *onset* competitor.

The results from the studies presented so far suggest that using pseudowords may be a more sensitive measure when investigating spoken-word recognition in infants than using real words. This may be due to two reasons: Using real words with 2-year-old infants heavily limits the range of possible words that can be used to design the study. This is especially the case when working with rhymes, real-world picturable objects and when one is trying to limit the variety of word lengths by using only monosyllabic words. Furthermore, it is possible that the use of real words may lead to lexical information of the spoken words overshadowing any possible phonological effects that could be observed when using pseudowords. Future research may therefore consider pref-

erentially using pseudowords when attempting to investigate infants' timing of spoken-word processing.

Finally, against expectations, infants did not show earlier, higher and longer-lasting looking proportions towards *rhymes* in the *rhyme close* condition where the onsets of the spoken word and the *rhyme* competitor only differed in terms of voicing than in the *rhyme distant* condition. This is in contrast with findings from the present adult studies (see Experiment 3) and from infant studies such as White & Morgan (2008) who have previously demonstrated linearly graded sensitivity to the degree of mismatch when presenting 19-month-old infants with mispronunciations. However, the present findings confirm previous studies which have demonstrated that mispronunciations involving multiple feature changes are not more disruptive to 23-month-olds' lexical access than mispronunciations with single feature changes (Bailey & Plunkett, 2002). A more recent study by Tamasi et al. (2019), on the other hand, showed that infants as young as 30 months do in fact show gradient sensitivity to phonological mismatch using looking time data as well as pupil dilation methodologies. The authors demonstrated that when presenting infants with small feature changes, they displayed relatively stable preference for the target whereas decreasing the phonological similarity between spoken word and label of the visual object lead to increasingly oscillating looking behaviour. They further showed that pupil dilation may be a more robust and sensitive measure of subphonemic representations than looking times. Taken together, the con-

flicting evidence suggests that while 2-year-olds' lexical representations may already distinguish sub-phonemic details, these representation do not seem to be as strong as for adults. It is possible that very sensitive measures such as pupil dilation methodologies are needed in order to reveal 2-year-olds' representations of sub-phonemic details. While 2-year-olds' lexical representations seem to be able to distinguish sub-phonemic details to some degree, it may be beneficial for infants at this age to allow for a greater degree of flexibility of sub-phonemic details. Such flexibility may allow infants to quickly adapt their current knowledge as they broaden their vocabulary during language learning.

Chapter 8

Experiment 7: TRACE vs. FUL

8.1 Introduction

Results from previous experiments of this thesis have partly supported interactive-activation models of spoken-word processing in adults such as the TRACE model (McClelland & Elman, 1986). The TRACE model suggests that upon hearing spoken words, various lexical candidates are activated in parallel and compete with each other through inhibitory and excitatory connections. The strength of concurrent activation of two words should therefore be correlated with the degree of phonological overlap between these two words. Present experiments have supported this idea demonstrating that upon hearing a target word, adults initially preferentially fixate on images that share the same on-

set as the spoken word which is followed by increased higher and longer lasting looking proportions towards objects that rhyme with the spoken word. The TRACE model assumes that the more similar two phonemes sound, the stronger the activation of inhibitory and excitatory connections are between these two phonemes. It does not, however, make any claims regarding the strength of these connections depending on their directions. Instead, it assumes that one phoneme will activate another with the same strength as an activation in the opposite direction.

In contrast, the Featurally-Underspecified Lexicon account (FUL, Lahiri & Reetz (2010)) suggests that these mutual activations may in fact differ in their potential strengths. More specifically, the FUL proposes that the strength of these activations may differ in particular regarding coronal/non-coronal phonemes. In order to understand this concept, one should note that English consonants are distinguished regarding their place and manner of articulation and whether they are voiced or unvoiced. The place of articulation is further subdivided into coronal and non-coronal phonemes. Coronal phonemes are produced using the flexible front part of the tongue while non-coronals are produced without raising this part of the tongue. The FUL (Lahiri & Reetz, 2010) suggests that there is an asymmetry in adults' representations of these coronal and non-coronal features. More specifically, it claims that while non-coronals can activate other non-coronals as well as coronals, coronals themselves are only able to activate other coronals. This is due to the assumption that coronals are underspecified according to

the FUL.

The aim of the present study was therefore to test the hypothesis that adults may be faster looking at a *rhyme* competitor when the spoken word starts with a non-coronal phoneme and the *rhyme* object starts with a coronal phoneme as opposed to reversed trials. The rationale behind this is the idea that coronals may already have been activated through excitatory connections when preceded by a non-coronal target word, thereby facilitating object recognition. Confirmation of this hypothesis would mean that interactive-activation models such as the TRACE model may need to be extended in order to take into account the strength of connections between different phonemes dependent on the direction in which phonemes become activated.

8.2 Methods

8.2.1 Participants

Data from 24 adults was included in this study. Adult participants were native English speakers aged between 18.04 and 33.68 years (M = 22.11, SD = 4.31) who were recruited from the University of Oxford.There were 17 females and 7 males. All participants reported normal or corrected-to-normal vision and no history of language or hearing impairments. Data from an additional 3 adults was removed for analysis due to problems with data recording (2) and problems tracking the participant's eye (1).

8.2.2 Design

In order to investigate the time course of looking proportions to images that rhyme with target auditory words to varying degrees, eye movements were recorded in a visual world paradigm displaying two pictures. The experiment consisted of two types of trials: **target absent** trials which served as experimental trials and **target present** trials which were used as filler trials. All stimuli used were imageable monosyllabic words.

On **target absent** trials, the object that participants were instructed to look at was not present among the two pictures displayed on the screen. Instead, one object rhyming with the spoken word was shown together with an *unrelated* distractor that was neither phonologically nor semantically related to the target word. The first phoneme of the phonologically *unrelated* distractor was always identical to the first phoneme of the *rhyme* competitor ensuring that the two words only differed in their nucleus and coda. The **target absent** trials themselves were subdivided into various conditions.

For one set of conditions, the **first phoneme** of the *rhyme* competitor was manipulated in one of three ways: it either differed from the first phoneme of the spoken word only in terms of voicing (*voice mismatch* condition, 44 trials), was a coronal/non-coronal mismatch from the first phoneme of the spoken word (*NC/C mismatch* condition, 44 trials) or differed from the first phoneme of the spoken word in terms of place, voicing and manner (*complete mismatch* condition, 44 trials).

The *NC/C mismatch* condition included trials of both directions: for half the trials (22) of the *NC/C mismatch* condition, the onset of the spoken word was a coronal and the onset of the *rhyme* competitor was a non-coronal, while this relationship was reversed for the remaining half of the *NC/C mismatch* trials (22).

In a second set of conditions, the phonological similarity of the **vowels** between the spoken word and the *unrelated* distractor was manipulated in three ways: the two vowels were either identical (*complete match* condition, 30 trials), were not identical but had the same vowel height (*height match* condition, 48 trials) or were not identical and mismatched in terms of vowel height (*height mismatch* condition, 54 trials). This was done in order to investigate whether vowel similarity between the spoken word and the *unrelated* distractor may modulate looking proportions towards the *rhyme* competitor.

On **target present** trials, the object that participants were instructed to look at was among the two pictures displayed; together with one distractor object that was phonologically, visually and semantically unrelated to the target object. **Target present** trials served to prevent participants from getting frustrated by the absence of target objects and from detecting the relationship between target words and phonological competitors.

In total, there were 132 experimental trials and 258 filler trials. Eye movements were recorded using an EyeLink 1000 automated eye-tracker. Looking proportions per time bin to the different types of

rhyme competitors and *unrelated* distractors served as the dependent variable as well as button responses and their respective reaction times.

8.2.3 Stimuli

Each participant was presented with a different randomised list of the trials. Whenever an object appeared in more than one trial, a different image of this object was presented for each trial. For an overview of the experimental trials used for this experiment, see Table E.3.

8.2.4 Procedure

On each trial, participants were first presented with a fixation cross in the middle of the screen for 1200ms. During this time, participants heard the spoken target word. A two picture display appeared immediately after the offset of the spoken word and stayed on the screen for 500ms (see Figure 8.1). Participants were instructed to use a two-button response box to indicate whether the word they heard was represented by the image on the left or on the right. Eye-tracking behaviour and button responses were recorded for another 1000ms after the images disappeared from the screen.

The experiment was split evenly into three blocks consisting of 130 trials each. Each block started with a 9-point calibration of the eye-tracker and participants were given short breaks between blocks.

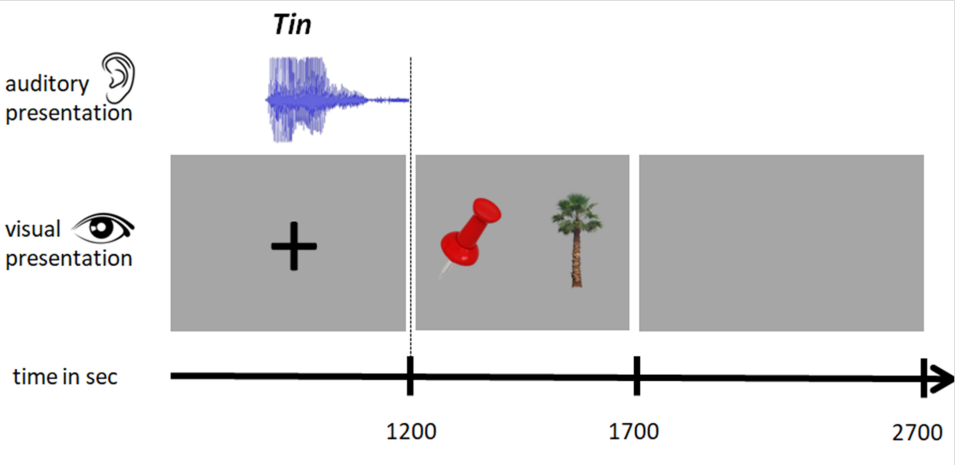


Figure 8.1: Example Trial: Participants hear the word "tin" followed by a visual display showing the image of a "pin" (*rhyme* competitor) and a "palm" (*unrelated* distractor).

8.2.5 Analysis

Looking proportions were calculated and statistical analyses of the eye-tracking data was carried out in the same way as in Experiment 1. When analysing participants' button responses, proportions were calculated for how often they incorrectly indicated that the *rhyme* competitor matched the spoken target word ('target response'). Mean reaction times were calculated separately for each condition regardless of the type of response participants gave. Overall, four types of possible effects were examined. In a first step, it was analysed whether a general *rhyme* effect could be observed with the present setup. A second step of analysis concerned the theory originating from the FUL account and investigated whether the order of presentation of coronal/non-coronal phonemes modulated the *rhyme* effect. The third analysis examined whether the similarity between the first phoneme of the spoken word

and the *rhyme* competitor had an impact on the *rhyme* effect. A final analysis step investigated how the phonological similarity between the vowels of the spoken word and the *unrelated* distractor may have impacted the *rhyme* effect.

8.3 Results

8.3.1 *Rhyme* Effect

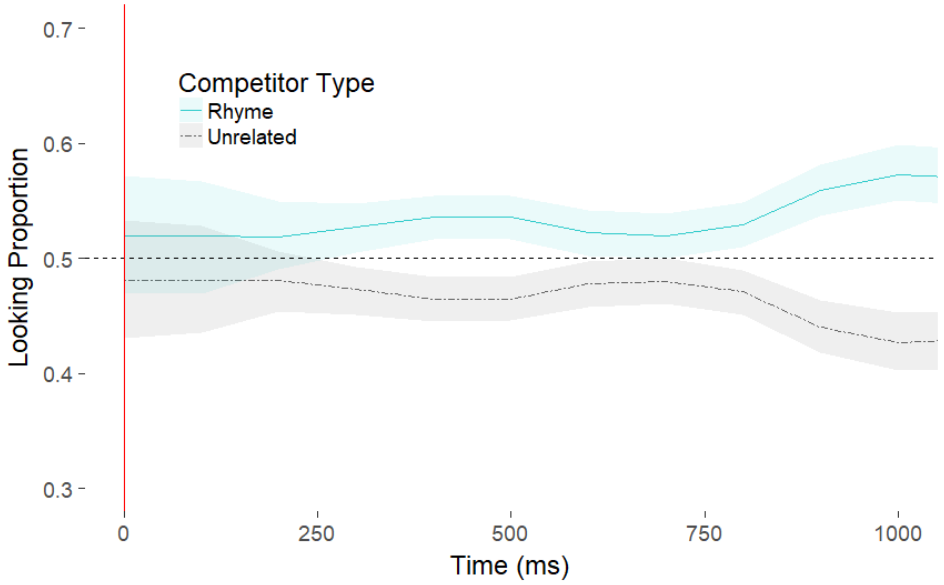


Figure 8.2: Overall Looking Proportions towards *rhyme* competitors and *unrelated* distractors.

Figure 8.2 shows looking proportions towards *rhyme* competitors and *unrelated* distractors starting from the onset of the visual display. It can be seen that looking proportions to the *rhyme* competitor start

increasing around 300ms after the onset of the visual display and remain increased for the entire duration of its presentation as well as for the time after the visual display has disappeared. In order to determine whether looking proportions towards the *rhyme* competitor were higher than chance level, a one-sampled t-test was run between looking proportions to the *rhyme* competitor and chance level of 0.5 for a time window between 0-1500ms after onset of the target word. Mean looking proportions to *rhyme* competitors (0.548) were significantly higher than chance level, $t(25443) = 15.792$, $p < 0.001$, $d = 0.100$.

8.3.2 Effect of Direction for Coronal/Non-Coronal Condition

In order to investigate whether adults are faster looking at a *rhyme* competitor when the spoken word starts with a non-coronal phoneme and the *rhyme* competitor starts with a coronal phoneme as opposed to reverse trials, looking proportions in the *NC/C mismatch* condition were compared depending on whether the spoken word started with a coronal or a non-coronal phoneme.

The overall time course of looking proportions to the *rhyme* competitor in the *NC/C mismatch* condition between 0-1500ms after the offset of the target word was modelled with second-order orthogonal polynomials and fixed effect of *direction* on all time terms. The *forward* condition (coronal to non-coronal) was treated as the baseline and parameters were estimated for the *reverse* condition (non-coronal to

coronal). The model also included random effects of participants on all time terms. Figure 8.3 displays the model for looking proportions to the *rhyme* competitor under the two different **direction** conditions. The figure suggests earlier and higher increased looking proportions in the *forward (coronal to non-coronal)* condition as compared to the *reverse (non-coronal to coronal)* condition. The results of the statistical model are summarised in Table 8.1. There was a significant quadratic term for the *reverse* condition suggesting that the trajectory of looking proportions towards the *rhyme* competitor differed depending on whether participants heard a coronal and saw an object that started with a non-coronal phoneme or the reverse direction.

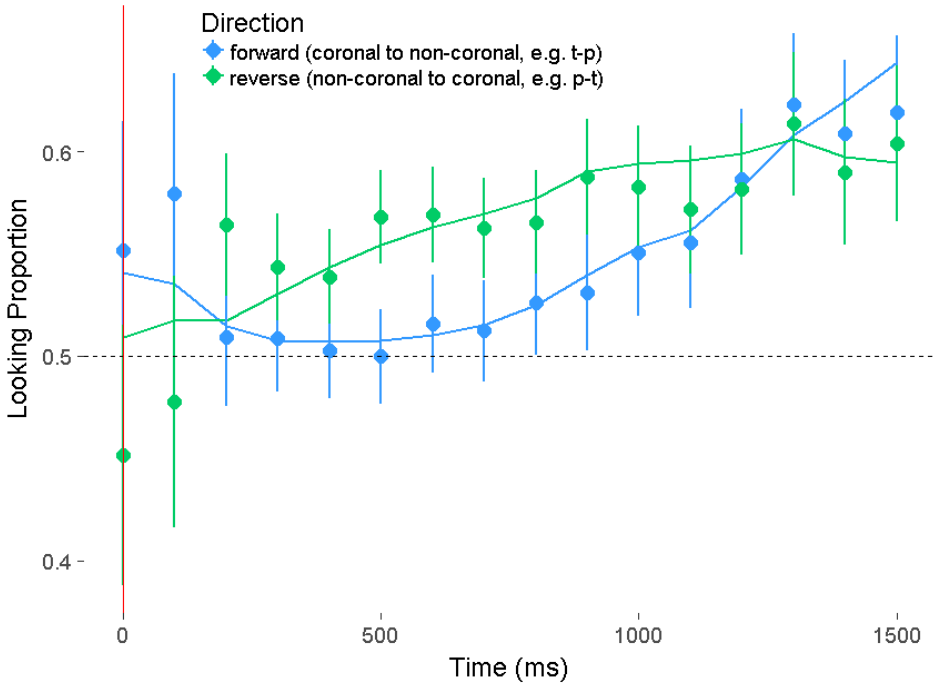
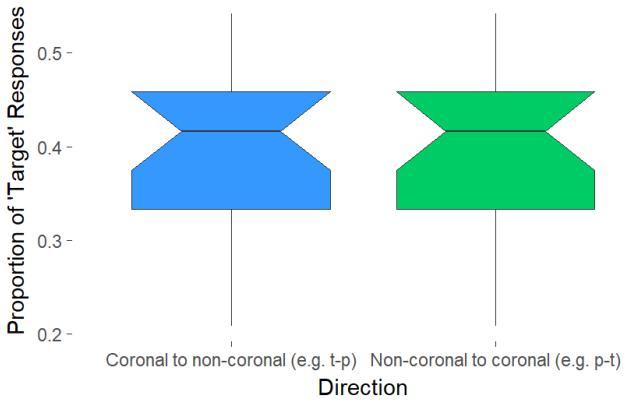


Figure 8.3: Growth curve analysis for the third model with fixed effect of direction. Points represent data and lines display the model.

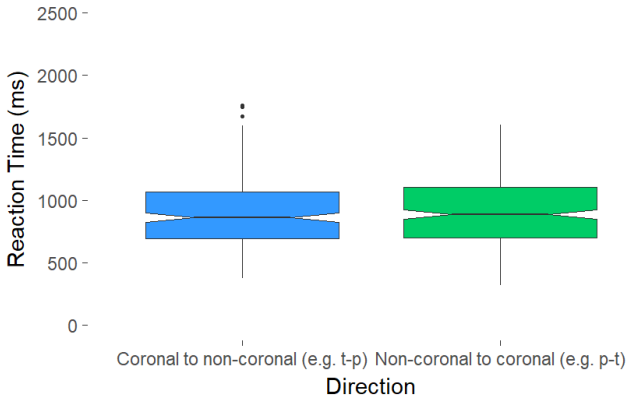
Fixed Effects	Model Terms	Est. (SE)	*t*	*p*
Reverse Condition	Intercept	0.07(0.05)	1.45	0.146
	Linear	-0.07(0.23)	-0.29	0.771
	Quadratic	-0.56(0.23)	-2.44	0.015*
		***p<.001, **p<.01, *p<.05		

Table 8.1: Results of the third model with fixed effect of direction.

In order to examine whether manipulating the **direction** of the *NC/C* mismatch had an impact on participants' responses and reaction times, Welch's two-sample t-tests were conducted on participants' responses and reaction times for the two different directions for *NC/C mismatch* trials. Welch's two-sample t-test showed that the difference in target responses between the *coronal to non-coronal* (M = 0.39, SD = 0.09) and the *non-coronal to coronal* condition (M = 0.39, SD = 0.10) was not significant, $t(42.00)$= -0.27, p = 0.792, d = 0.080). Figure 8.4a displays proportion of 'target' response for the two different directions. Welch's two-sample t-test showed that the difference in reaction times between the *coronal to non-coronal* (M = 907.18, SD = 291.32) and the *non-coronal to coronal* condition (M = 922.42, SD = 360.23) was not significant, $t(506.61)$= -0.53, p = 0.594, d = 0.046. Figure 8.4b displays reaction times for the two different directions.



(a) Response



(b) Reaction Time

Figure 8.4: Behavioural responses across the different directions for the NC/C mismatch condition.

8.3.3 Effect of First Phoneme

The overall time course of looking proportions to the *rhyme* competitor between 0-1500ms after the offset of the target word was modelled with third-order orthogonal polynomials and fixed effect of *first phoneme* on all time terms. Looking proportions to the *rhyme* competitor were concatenated for the *complete mismatch* condition and treated as

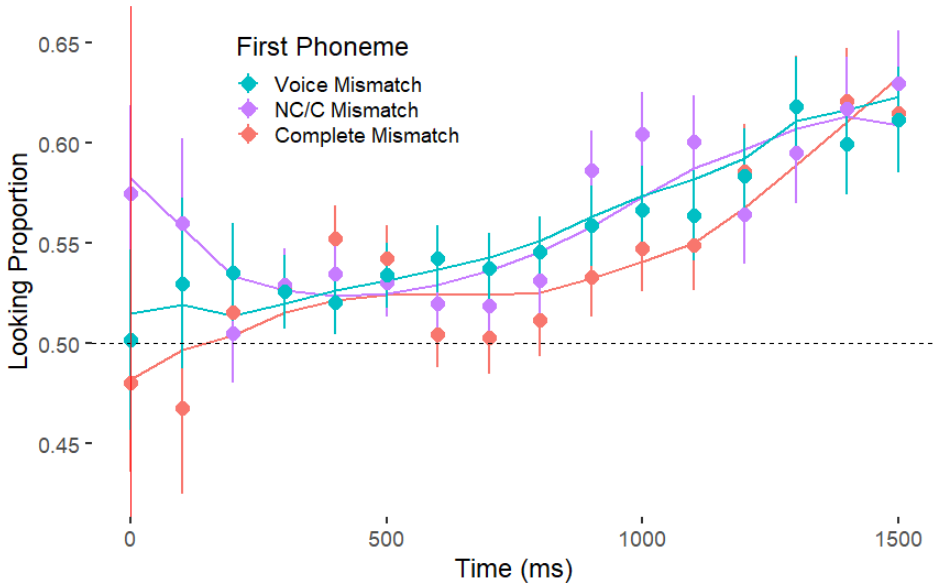


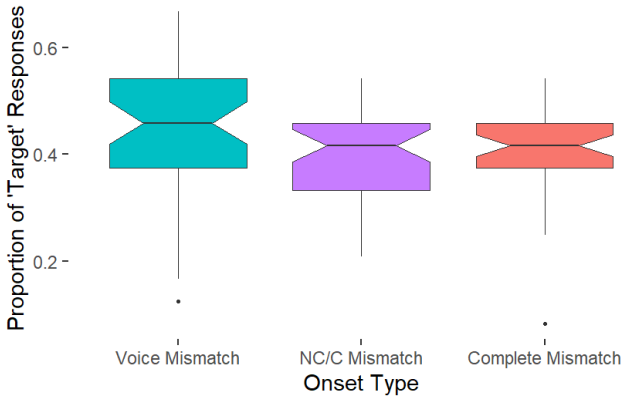
Figure 8.5: Growth curve analysis for the first model with fixed effect of first phoneme. Points represent data and lines display the model. The NC/C mismatch condition includes trial types on which the onset of the spoken word was a coronal and the onset of the *rhyme* competitor was a non-coronal as well as trials where this relationship was reversed.

the baseline. Parameters were estimated for the *voice mismatch* and *NC/C mismatch* conditions. The model also included random effects of participants on the intercept and linear terms. Figure 8.5 displays the model for looking proportions to the *rhyme* competitor under the three different **first phoneme** conditions. The figure suggests lower looking proportions in the *complete mismatch* condition as compared to the *voice mismatch* and *NC/C mismatch* conditions. The results of the statistical model are summarised in Table 8.2.

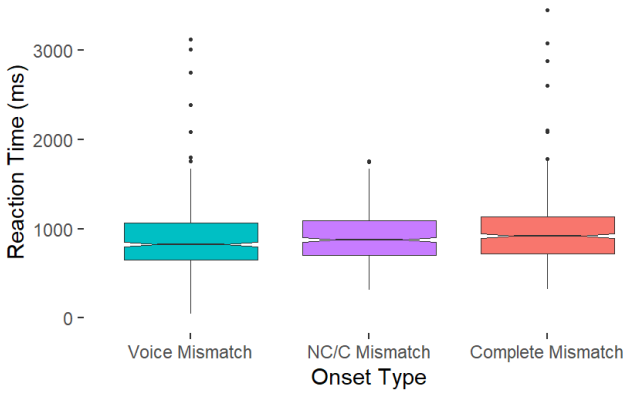
Fixed Effects	Model Terms	Est. (SE)	*t*	*p*
Voice Mismatch	Intercept	0.10(0.04)	2.59	0.010*
	Linear	-0.21(0.18)	-1.19	0.233
	Quadratic	0.09(0.16)	0.58	0.560
	Cubic	-0.39(0.15)	-2.54	0.011*
NC/C Mismatch	Intercept	0.08(0.04)	2.24	0.025*
	Linear	0.04(0.18)	0.21	0.838
	Quadratic	-0.05(0.16)	-0.33	0.740
	Cubic	-0.21(0.16)	-1.38	0.167
		***p<.001, **p<.01, *p<.05		

Table 8.2: Results of the first model with fixed effect of first phoneme and the *complete mismatch* condition as baseline.

The intercepts were significant for both conditions suggesting that, in general, looking proportions were higher in the *voice mismatch* and the *NC/C mismatch* conditions as compared to the *complete mismatch* condition. Furthermore, there was a significant cubic term for the *voice mismatch* condition suggesting that looking proportions in the *voice mismatch* condition may have followed a slightly different trajectory than looking proportions in the *complete mismatch* condition. None of the other linear, quadratic or cubic terms showed a trend towards significance.



(a) Response



(b) Reaction Time

Figure 8.6: Behavioural responses across the different first phoneme conditions.

In order to examine whether manipulating the **first phoneme** of the *rhyme* competitor had an impact on participants' responses and reaction times, ANOVAs and t-tests were conducted on participants' responses and reaction times for the three different conditions. A one-way within subjects ANOVA showed that the effect of **first phoneme** on target response was significant, $F(2,129) = 3.08$, $p = 0.0495$,$\eta^2 = 0.046$. Post-hoc comparisons using the Tukey HSD test indicated that 'target'

response proportions for the *voice mismatch* condition ($M = 0.44$, $SD = 0.13$) were significantly higher than for the *NC/C mismatch* condition ($M = 0.39$, $SD = 0.09$) at $p = 0.049$. The *complete mismatch* condition ($M = 0.40$, $SD = 0.08$) did not differ significantly from either the *voice mismatch* ($p = 0.172$) or the *NC/C mismatch* condition ($p = 0.835$). Figure 8.6 displays proportion of 'target' responses for the three different types of first phonemes.

A one-way within subjects ANOVA showed that the effect of **first phoneme** on reaction time was significant, $F(2,1636) = 4.43$, $p = 0.012$, $\eta^2 = 0.005$. Post-hoc comparisons using the Tukey HSD test indicated that mean reaction time for the *voice mismatch* condition ($M = 886.52$, $SD = 389.39$) were significantly faster than for the *complete mismatch* condition ($M = 950.35$, $SD = 349.05$) at $p = 0.008$. However, the *NC/C mismatch* condition ($M = 914.87$, $SD = 328.28$) did not differ significantly from either the *voice mismatch* ($p = 0.386$) or the *complete mismatch* condition ($p = 0.239$). Figure 8.6b displays reaction times for the three different types of first phonemes.

8.3.4 Effect of Vowel

The overall time course of looking proportions to the *rhyme* competitor between 0-1500ms after the offset of the target word was modelled with third-order orthogonal polynomials and fixed effect of *vowel* on all time terms. The *complete match* condition was treated as the baseline and parameters were estimated for the *height mismatch* and *height match*

conditions. The model also included random effects of participants on the intercept and linear terms. Figure 8.7 displays the model for looking proportions to the *rhyme* competitor under the three different **vowel** conditions. The figure suggests lower looking proportions in the *complete match* condition as compared to the *height mismatch* and *height match* conditions.

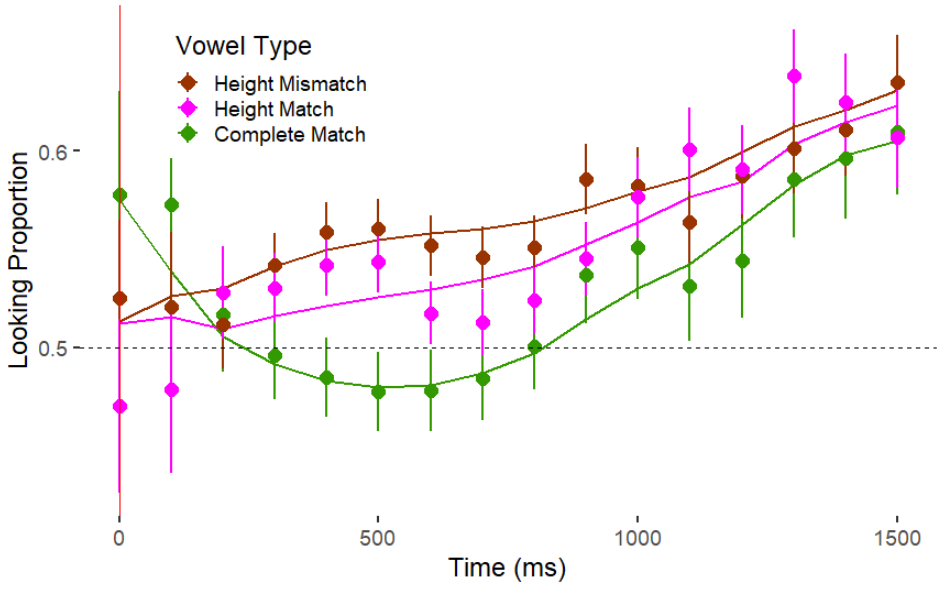


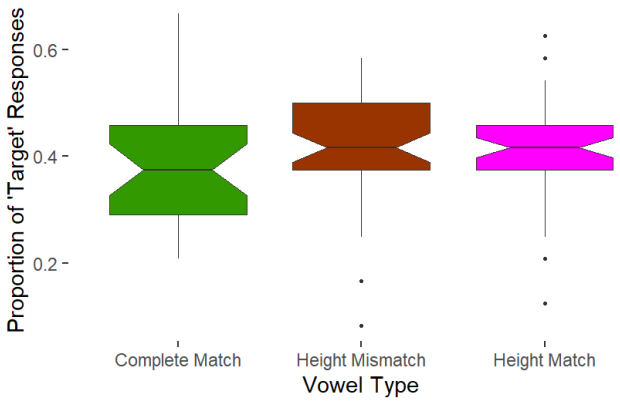
Figure 8.7: Growth curve analysis for the second model with fixed effect of vowel. Points represent data and lines display the model. In the *complete match* condition, the vowel of the spoken word and the *unrelated* distractor were identical; in the *height match* condition they had the same vowel height whereas in the *height mismatch* condition they differed in vowel height.

The results of the statistical model are summarised in Table 8.3. There were significant intercepts for the *height match* and *height mismatch* conditions suggesting that overall looking proportions towards the *rhyme* competitor were lower in the *complete match* condition than

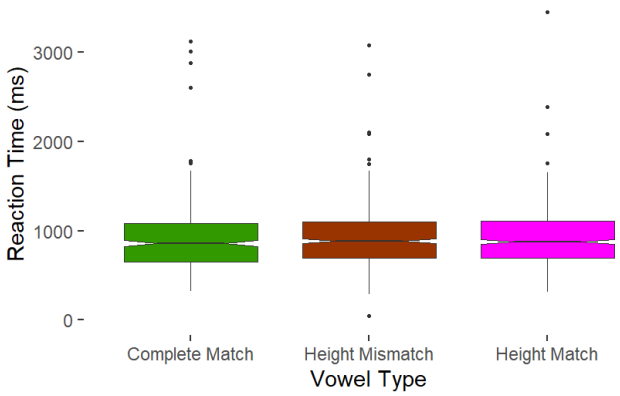
in the other two conditions. Furthermore, there was a significant quadratic term for the *height mismatch* condition as well as a trend towards a significant quadratic term for the *height match* condition suggesting that the time course of looking proportions towards the *rhyme* competitor may differ slightly in these conditions as compared to the *complete match* condition.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Height Mismatch	Intercept	0.17(0.04)	4.25	<.001***
	Linear	0.19(0.19)	0.98	0.325
	Quadratic	-0.45(0.17)	-2.60	0.009**
	Cubic	0.29(0.16)	1.77	0.076
Height Match	Intercept	0.10(0.04)	2.54	0.011*
	Linear	0.24(0.20)	1.25	0.211
	Quadratic	-0.33(0.18)	-1.88	0.059
	Cubic	0.20(0.17)	1.18	0.238
		***p<.001, **p<.01, *p<.05		

Table 8.3: Results of the second model with fixed effect of vowel type and the *complete match* condition as baseline.



(a) Response



(b) Reaction Time

Figure 8.8: Behavioural responses across the different vowel conditions.

In order to examine whether manipulating the **vowel** of the *unrelated* distractor had an impact on participants' responses and reaction times, ANOVAs and t-tests were conducted on participants' responses and reaction times for the three different conditions. A one-way within subjects ANOVA showed that the effect of vowel type on target response was not significant, $F(2,129) = 2.15$, $p = 0.121$, $\eta^2 = 0.032$. Figure 8.8a displays proportion of 'target' response for the three different vowel types. Furthermore, a one-way within subjects ANOVA showed that

the effect of vowel type on reaction time was not significant, $F(2,1636) = 0.703$, $p = 0.495$, $\eta^2 = 0.001$. Figure 8.8b displays reaction times for the three different vowel types for the *unrelated* distractor.

8.4 Discussion

Results from this experiment revealed that adults look more at *rhyme* competitors than *unrelated* distractors when presented with two images and not being given any time to inspect the images before hearing the target word. Results further showed that adults were faster looking at a *rhyme* competitor when they heard a spoken word that started with a non-coronal phoneme and saw an image who's label started with a coronal phoneme (e.g. *p* - *t*) as opposed to hearing a word that started with a coronal phoneme and seeing an image with a label that started with a non-coronal phoneme (e.g. *t* - *p*). Furthermore, the present study revealed that adults looked significantly less at such *rhyme* competitors when the first phoneme of the rhyme was different from the first phoneme in terms of place, voicing as well as manner as compared to when the two phonemes only differed in terms of voicing or only in terms of place. Finally, results from the present study revealed that adults looked considerably less at such *rhyme* competitors when the *unrelated* distractor shared its vowel with the spoken word and the *rhyme* competitor as compared to trials on which the vowels only had the same vowel height or trials on which they differed in vowel height.

Our findings that participants look more at the *rhyme* competitor than the unrelated distractor with the present setup further support the idea that a previewing of the visual display is not necessary in order to elicit phonological effects in adults. In the present setup, adults heard the entire target word before they saw the visual display, giving them no time to implicitly name the images. The present results therefore further contradict the idea proposed by Huettig & McQueen (2007) that pre-viewing of the images is required in order to elicit phonological effects in adults. One possible reason why the present results differ from the results presented by Huettig & McQueen (2007) could be that the latter also included images that were either semantically or visually related to the spoken word - these images may have attracted enough attention overshadowing phonological effects when adults had not already pre-activated the phonological codes for the images presented.

The main aim of this experiment was to investigate whether it is mainly the phonological similarity between a spoken word and an image that drives adults' attention or whether the direction of this relationship matters as well. According to the TRACE model (McClelland & Elman, 1986), there are excitatory and inhibitory connections between phonemes that sound similar. It is for this reason that upon encountering phonemes of a word, phonemes that are phonologically similar become activated as well. The TRACE model makes no claim regarding the direction of these excitatory connections. Hearing a *t* should therefore activate a *p* in the same way that hearing a *p* would acti-

vate a *t*. However, the FUL theory (Lahiri & Reetz, 2010) states that directions do in fact matter due to an asymmetry in adults' representation of coronal and non-coronal features. The present findings indicate that adults are in fact faster looking at a *rhyme* competitor that starts with a non-coronal phoneme when they have previously heard a word that started with a coronal phoneme as opposed to the opposite direction. These results support the ideas of the FUL theory and therefore suggest that interactive-activation models of spoken-word recognition such as the TRACE model (McClelland & Elman, 1986) may need to be extended in order to also include the strength of directions of the inhibitory as well as excitatory connections that form basis of these models.

The findings that adults spend less time fixating on objects that rhyme with a spoken word when their first phonemes differ in terms of voicing, place and manner as compared to differences only in term of voicing or only in terms of place confirm results from Experiment 3 of this thesis where looking proportions to *rhyme* competitors differed depending on how similar the first phonemes of the spoken word and the rhyming object were. Furthermore, adults were more likely to indicate that the *rhyme* competitor matched the spoken word and were faster in making such decisions when the first phonemes of the spoken word and the *rhyme* competitor only differed in terms of voicing as compared to more obvious differences. Taken together, these results further confirm the theory that the amount of phonological similarity at the beginning

of a word influences the amount of attention a *rhyme* competitor elicits and underlines the importance of the initial phoneme of a word in the process of spoken-word recognition (Connine et al., 1993). In this thesis, we have not been able to demonstrate similar effects in 2-year-olds.

Finally, the present results that looking proportions to *rhyme* competitors were lower when the *unrelated* distractor shared its vowel with the spoken word and the *rhyme* competitor further support our hypothesis resulting from Experiment 1 that not only the phonological similarity between spoken word and *rhyme* competitor modifies looking proportions towards the *rhyme* competitor but that the phonological similarity between spoken word and *unrelated* distractor also plays a crucial role. Despite the *unrelated* distractor not being directly phonologically related to the spoken word, its relative similarity to the spoken word can deviate attention away from the *rhyme* competitor towards the *unrelated* distractor thereby influencing overall looking proportions. These findings are crucial for future studies employing a visual world paradigm to investigate spoken-word recognition. While researchers have traditionally been extremely careful about controlling for possible artefacts when choosing their experimental stimuli, such considerations have mainly been focused on the manipulated stimuli rather than stimuli that served only as baseline measures. The present findings serve as a reminder for researchers that even seemingly neutral stimuli may have an impact on effects created by the carefully selected experimental stimuli.

Chapter 9

Experiment 8: Effects of *Unrelated* Distractors

9.1 Introduction

Previous experiments of this thesis have mainly been concerned with manipulating either *onset* or *rhyme* competitors in order to investigate how objects with labels that are phonologically related to a spoken word may drive infants' and adults' attention during spoken-word recognition. Much like previous research in the field, less emphasis has been placed on manipulating the phonological similarity between spoken words an *unrelated* distractors in order to further understand the effects of phonological competition during spoken-word recognition. Post-hoc analysis from *Experiment 1*, however, suggested that the first phoneme of *unrelated* distractors may modulate the magnitude of the

onset effect for adults in a visual world paradigm. Namely, if the onset of an *unrelated* distractor was phonologically very similar to the onset of the spoken word, looking proportions to the *onset* competitor were decreased as compared to trials in which the first phoneme of the *unrelated* distractor was phonologically dissimilar to the onset of the spoken word. It is possible that in cases where the onset of a seemingly *unrelated* distractor is quite similar to the onset of a spoken word, this *unrelated* distractor may drive attention away from the phonologically related *onset* competitor, hence, decreasing looking proportions towards the latter. Despite this being a plausible explanation, there is a lack of studies explicitly manipulating the phonological similarity between a spoken word and the *unrelated* distractor. The aim of the present experiment was therefore to carefully manipulate the relationship between the onsets of spoken words and *unrelated* distractors in order to investigate the hypothesis that even seemingly phonologically *unrelated* distractors may modulate attention during spoken-word recognition in a visual world paradigm.

Furthermore, the present experiment will expand on the line of research presented in Experiment 7 regarding the representation of coronal and non-coronal phonemes as first suggested by the FUL account (Lahiri & Reetz, 2010). More specifically, the FUL account proposes that there is an asymmetry in adults' representations of coronal and non-coronal features. In particular, it claims that while non-coronals can activate other non-coronals as well as coronals, coronals themselves are only

able to activate other coronals. This is due to the assumption that coronals are underspecified according to the FUL. Experiment 7 has already confirmed this hypothesis and the present experiment will aim to determine whether this account also holds true when manipulating *unrelated* distractors. Following the assumptions of the FUL account, participants should be faster looking at *onset* competitors when they first hear a spoken word that starts with a coronal phoneme and then see an *onset* competitor together with an *unrelated* distractor that starts with a non-coronal phoneme as opposed to the reverse direction. The rationale behind this is that if coronal phonemes do not activate non-coronal phonemes with the same strength that non-coronal phonemes activate coronal phonemes, then upon hearing a spoken word that starts with a coronal phoneme, participants' activation of the non-coronal first phoneme of the *unrelated* distractor should be relatively low and thereby reducing the amount with which the *unrelated* distractor may drive attention away from the *onset* competitor.

Taken together, the present experiment aims to evaluate the hypothesis generated in Experiment 1 that the onset of *unrelated* distractors may modulate looking proportions towards *onset* competitors and aims to determine whether this modulation is influenced by the assumptions made by the FUL account (Lahiri & Reetz, 2010).

9.2 Methods

9.2.1 Participants

Data from 24 adults was included in this study. Adult participants were native English speakers aged between 18.54 and 39.11 years (M = 22.83, SD = 5.42) who were recruited from the University of Oxford. There were 17 females and 7 males. All participants reported normal or corrected-to-normal vision and no history of language or hearing impairments.

9.2.2 Design

In order to investigate whether the first phoneme of *unrelated* distractors modulates the time course of looking proportions to *onset* competitors, eye movements were recorded in a visual world paradigm displaying two pictures. The experiment consisted of two types of trials: **target absent** trials which served as experimental trials and **target present** trials which were used as filler trials. The stimuli list was created by modyfing the stimuli list from Experiment 7. Stimuli that served as a target word in Experiment 7 were used as *unrelated* distractors and stimuli that were used as a *rhyme* competitor in Experiment 7 served as *onset* competitors in the current experiment. Target pseudowords were created by using the first phoneme of the *onset* competitor and generating a monosyllabic pseudoword that does not exist in the English dictionary.

On **target absent** trials, participants heard a spoken pseudoword before seeing two images. Pseudowords were used because a pilot study had shown that no phonological effects could be found when using real words. It is possible that no phonological effects were found in the pilot study since the removal of the pre-naming phase might have significantly reduced the strength of any *onset* effects. This would be in line with findings from Experiment 3, in which the removal of the pre-naming phase lead to the disappearance of the *onset* effect. However, for the purpose of this experiment, we wanted to be able to manipulate more carefully when participants are processing auditory and visual information rather than having them process both types of information at the same time. We therefore decided to use pseudowords rather than increasing the pre-naming time for the present experiment in order to facilitate the occurence of *onset* effects. Among the images presented was one object that started with the same phoneme as the spoken pseudoword (i.e. an *onset* competitor) shown together with an *unrelated* distractor that was neither phonologically nor semantically related to the spoken pseudoword. The *unrelated* distractor always rhymed with the *onset* competitor in order to ensure that the only feature that differed between the two words was their onset.

The first phoneme of the phonologically *unrelated* distractor was manipulated in one of three ways: it either differed from the first phoneme of the spoken pseudoword only in terms of voicing (e.g. *bab - peach, voice mismatch* condition, 44 trials), was a coronal/non-coronal mis-

match from the first phoneme of the spoken pseudoword (*pise - till, NC/C mismatch* condition, 44 trials) or differed from the first phoneme of the spoken pseudoword in terms of place, voicing and manner (*shiff - bell, complete mismatch* condition, 44 trials). The *NC/C mismatch* condition included trials of both directions: for half the trials (22) of the *NC/C mismatch* condition, the onset of the spoken word was a coronal and the onset of the *unrelated* distractor was a non-coronal, while this relationship was reversed for the remaining half of the *NC/C mismatch* trials (22).

On **target present** trials, the object that participants were instructed to look at was among the two pictures displayed; together with one distractor object that was phonologically, visually and semantically unrelated to the target object. **Target present** trials served to prevent participants from getting frustrated by the absence of target objects and from detecting the relationship between target words and phonological competitors.

In total, there were 132 experimental trials and 258 filler trials. Eye movements were recorded using an EyeLink 1000 automated eye-tracker. Looking proportions per time bin to the different types of *onset* competitors and *unrelated* distractors served as the dependent variable as well as button responses and their respective reaction times.

9.2.3 Stimuli

Each participant was presented with a different randomised list of the trials. Whenever an object appeared in more than one trial, a different image of this object was presented for each trial. For an overview of the experimental trials used for this experiment, see Table F.3.

9.2.4 Procedure

On each trial, participants were first presented with a fixation cross in the middle of the screen for 1200ms. During this time, participants heard the spoken target or pseudoword. A two picture display appeared immediately after the offset of the spoken word and stayed on the screen for 500ms (see Figure 8.1). Participants were instructed to use a two-button response box to indicate whether the word they heard sounded more like the image on the left or on the right. Eye-movement behaviour and button responses were recorded for another 1000ms after the images disappeared from the screen.

The experiment was split evenly into three blocks consisting of 130 trials each. Each block started with a 9-point calibration of the eye-tracker and participants were given short breaks between blocks.

9.2.5 Analysis

Looking proportions were calculated and statistical analyses carried out in the same way as in Experiment 7. When analysing participants'

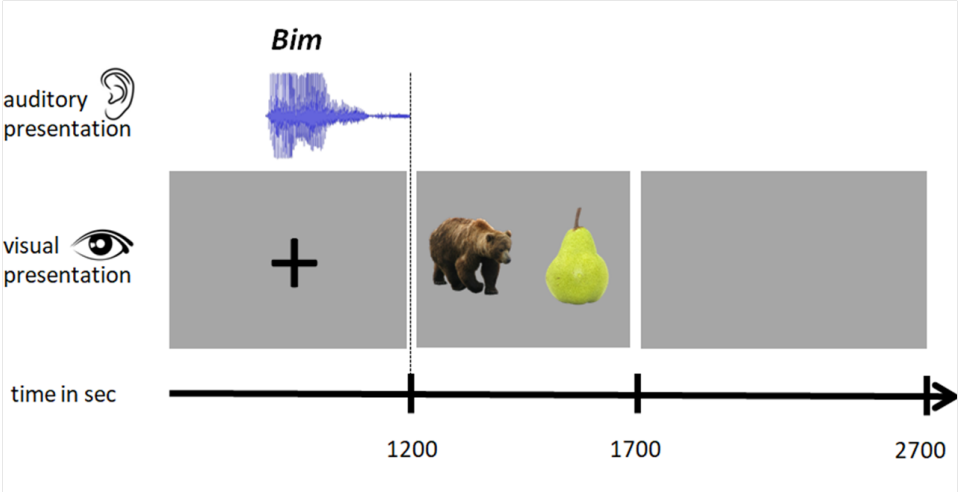


Figure 9.1: Example Trial

button responses, proportions were calculated for how often they incorrectly indicated that the *onset* competitor matched the spoken pseudoword ('target response'). Mean reaction times were calculated separately for each condition regardless of the type of response participants gave. Overall, three types of possible effects were examined. In a first step, it was analysed whether a general *onset* effect could be observed with the present setup. A second step of analysis examined whether the similarity between the first phoneme of the spoken word and the *unrelated* distractor had an impact on the *onset* effect. Finally, the third analysis concerned the theory originating from the FUL account and investigated whether participants were faster looking at an *onset* competitor when the spoken pseudoword started with a coronal phonemes an the *unrelated* distractor started with a non-coronal phoneme as opposed to reverse trials.

9.3 Results

9.3.1 *Onset* Effect

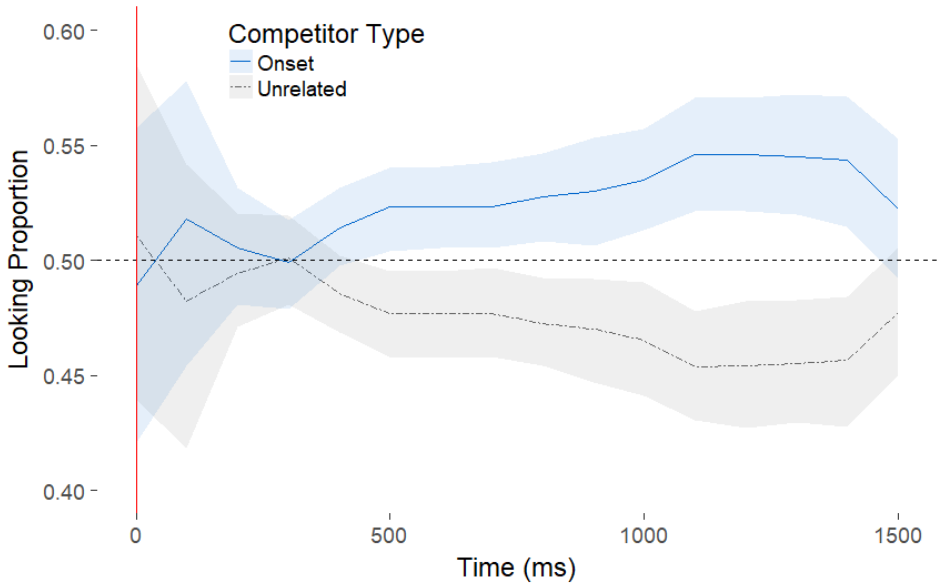


Figure 9.2: Overall Looking Proportions towards *onset* competitors and *unrelated* distractors.

Figure 9.2 shows looking proportions towards *onset* competitors and *unrelated* distractors starting from the onset of the visual display. It can be seen that while there is a trend for looking proportions to be higher for *onset* competitors than *unrelated* distractors, this difference is not as obvious as in Experiments 1, 2 and 3 of this thesis. In order to determine whether looking proportions towards the *onset* competitor were higher than chance level, a one-sampled t-test was run between looking proportions to the *onset* competitor and chance level of 0.5 for a time window between 0-1500ms after onset of the pseudoword.

Mean looking proportions to *onset* competitors (0.525) were significantly higher than chance level, $t(27569) = 8.433$, $p < 0.001$, $d = 0.051$.

9.3.2 Effect of First Phoneme

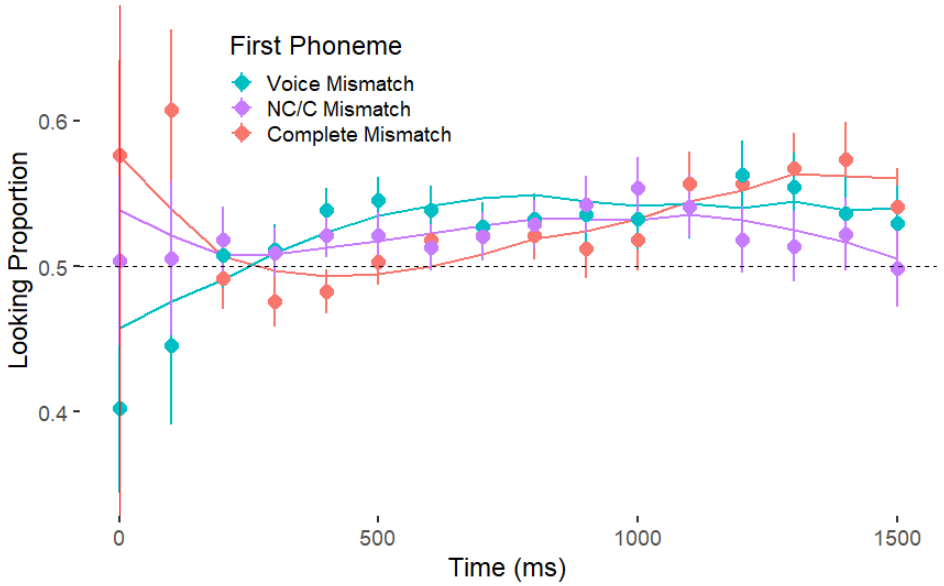


Figure 9.3: Growth curve analysis for the first model with fixed effect of first phoneme. Points represent data and lines display the model. The NC/C mismatch condition includes trial types on which the onset of the spoken word was a coronal and the onset of the *unrelated* distractor was a non-coronal as well as trials where this relationship was reversed.

The overall time course of looking proportions to the *onset* competitor between 0-1500ms after the offset of the pseudoword was modelled with third-order orthogonal polynomials and fixed effect of *first phoneme* of the *unrelated* distractor on all time terms. Looking proportions to the *onset* competitor in the *complete mismatch* condition were treated as

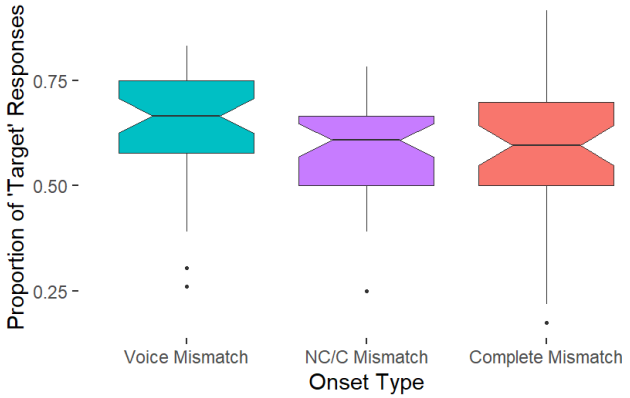
the baseline and parameters were estimated for the *voice mismatch* and *NC/C mismatch* conditions. The model also included random effects of participants on the intercept and linear terms. Figure 9.3 displays the model for looking proportions to the *onset* competitor under the three different **first phoneme** conditions. The figure suggests very similar patterns of looking proportions for all three conditions. The results of the statistical model are summarised in Table 9.1.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Voice Mismatch	Intercept	-0.00(0.04)	-0.08	0.933
	Linear	0.15(0.19)	0.76	0.448
	Quadratic	-0.51(0.17)	-2.96	0.003**
	Cubic	0.32(0.16)	1.94	0.052
NC/C Mismatch	Intercept	-0.03(0.04)	-0.79	0.427
	Linear	-0.20(0.19)	-1.04	0.296
	Quadratic	-0.36(0.17)	-2.06	0.039*
	Cubic	0.09(0.16)	0.54	0.587
		***p<.001, **p<.01, *p<.05		

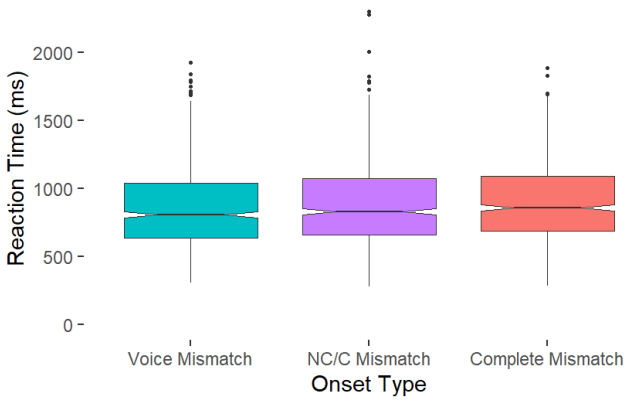
Table 9.1: Results of the first model with fixed effect of first phoneme and the *complete mismatch* condition as baseline.

None of the intercepts were significant suggesting that in general, looking proportions were not higher or lower in the *complete mismatch* condition than in either the *voice mismatch* or the *NC/C mismatch* conditions. There were significant quadratic terms for the *voice mismatch* and the *NC/C mismatch* conditions as well as a trend towards a significant cubic term for the *voice mismatch* condition suggesting that looking proportions in the *complete mismatch* condition followed

a slightly different trajectory than looking proportions in either the *voice mismatch* or the *NC/C mismatch* conditions



(a) Response



(b) Reaction Time

Figure 9.4: Behavioural responses across the different first phoneme conditions.

In order to examine whether manipulating the **first phoneme** of the *unrelated* distractor had an impact on participants' responses and reaction times, ANOVAs and t-tests were conducted on participants' responses and reaction times for the three different conditions. A one-way

within subjects ANOVA showed that the effect of **first phoneme** on target response was not significant, $F(2,129) = 1.64$, $p = 0.198$, $\eta^2 = 0.025$. Figure 9.4 displays proportion of 'target' responses for the three different types of first phonemes of the *unrelated* distractor.

A one-way within subjects ANOVA showed that the effect of **first phoneme** of the *unrelated* distractor on reaction time was significant, $F(2,2624) = 5.12$, $p = 0.006$, $\eta^2 = 0.004$. Tukey HSD test indicated that reaction times for the *voice mismatch* condition ($M = 858.48$, $SD = 288.83$) were significantly faster than for the *complete mismatch* condition ($M = 902.40$, $SD = 277.03$) at $p = 0.004$. The *coronal vs. non-coronal* condition ($M = 881.93$, $SD = 297.63$) did not differ significantly from either the *voice mismatch* ($p = 0.202$) or the *complete mismatch* condition ($p = 0.300$). Figure 9.4b displays reaction times for the three different types of first phonemes of the *unrelated* distractor.

9.3.3 Effect of Direction for Coronal vs. Non-Coronal Condition

In order to investigate whether adults are faster looking at an *onset* competitor when the spoken pseudoword starts with a coronal phoneme and the *unrelated* distractor starts with a non-coronal phoneme as opposed to reverse trials, looking proportions in the *coronal vs. non-coronal* condition were compared depending on whether the spoken pseudoword started with a coronal or a non-coronal phoneme. The overall time course of looking proportions to the *onset* competitor in the

coronal vs. non-coronal condition between 0-1500ms after the offset of the spoken pseudoword was modelled with second-order orthogonal polynomials and fixed effect of *direction* on all time terms. The *forward* condition (coronal to non-coronal) was treated as the baseline and parameters were estimated for the *reverse* condition (non-coronal to coronal). The model also included random effects of participants on all time terms. Figure 9.5 displays the model for looking proportions to the *onset* competitor under the two different **direction** conditions. The figure suggests that looking proportions towards the *onset* competitor were higher when the spoken pseudoword started with a coronal phoneme and the *unrelated* distractor started with a non-coronal phoneme (e.g. *t* - *p*) as compared to the reverse direction (e.g. *p* - *t*). The results of the statistical model are summarised in Table 9.2. There was a significant intercept confirming that looking looking proportions towards the *onset* competitor were higher when the spoken pseudoword started with a coronal phoneme and the *unrelated* distractor started with a non-coronal phoneme as compared to the reverse direction. None of the linear or quadratic terms were significant suggesting that the trajectory of looking proportions followed a similar pattern in both conditions.

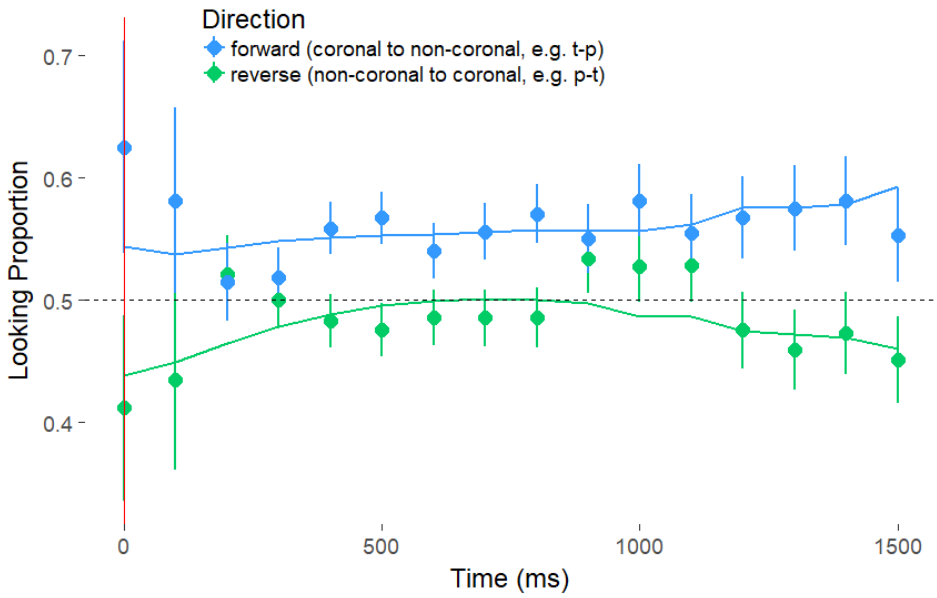


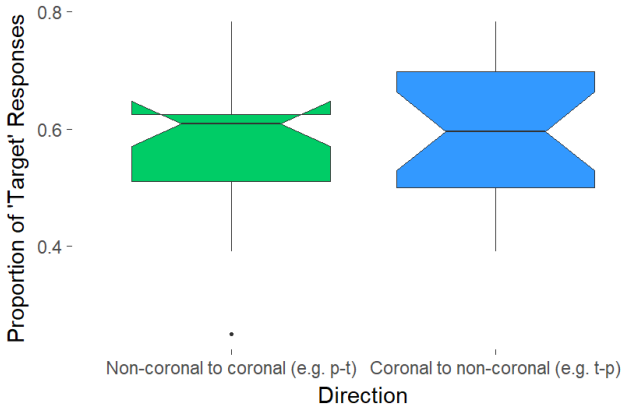
Figure 9.5: Growth curve analysis for the second model with fixed effect of direction. Points represent data and lines display the model.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Reverse Condition	Intercept	-0.33(0.05)	-6.79	<.001***
	Linear	-0.17(0.22)	-0.78	0.437
	Quadratic	-0.39(0.23)	-1.74	0.082
		***p<.001, **p<.01, *p<.05		

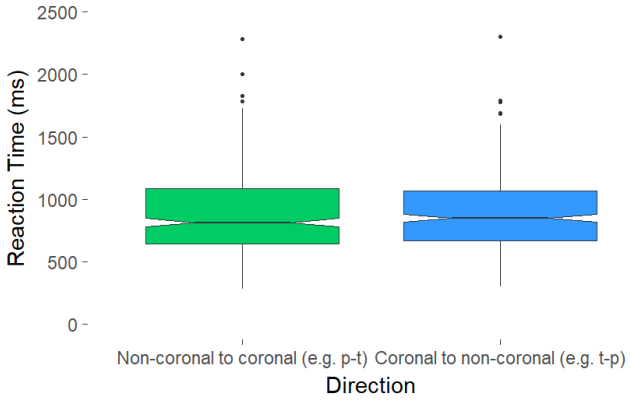
Table 9.2: Results of the second model with fixed effect of direction.

In order to examine whether manipulating the **direction** of the *coronal vs. non-coronal* condition had an impact on participants' responses and reaction times, Welch's two-sample t-tests were conducted on participants' responses and reaction times for the two different directions for *coronal vs. non-coronal* trials. Welch's two-sample t-test showed that the difference in target responses between the *coronal to non-coronal* ($M = 0.60$, $SD = 0.12$) and the *non-coronal to coronal* condition (M

= 0.58, SD = 0.13) was not significant, $t(41.62)$= -0.41, p = 0.685, d = 0.123). Figure 9.6a displays proportion of 'target' response for the two different directions. Welch's two-sample t-test showed that the difference in reaction times between the *coronal to non-coronal* (M = 887.00, SD = 283.76) and the *non-coronal to coronal* condition (M = 876.92, SD = 311.01) was not significant, $t(862.17)$= -0.50, p = 0.618, d = 0.034. Figure 9.6b displays reaction times for the two different directions.



(a) Response



(b) Reaction Time

Figure 9.6: Behavioural responses across the different directions for the coronal vs. non-coronal condition.

9.4 Discussion

Results of the present experiment revealed that while the phonological similarity between the onset of a spoken word and an *unrelated* distractor does not seem to modulate the general amplitude of looking proportions towards an *onset* competitor, it does seem to influence the trajectory of looking proportions towards the *onset* competitor. More specifically, there was a significant difference in the trajectory of these looking proportions between trials in which the first phoneme of the spoken word differed from the first phoneme of the *unrelated* distractor only in terms of voicing as compared to trials on which the two phonemes differed in terms of voicing, place and manner. Furthermore, there was a significant difference of this trajectory between trials in which the first phoneme of the spoken word and the *unrelated* distractor differed in terms of voicing, place and manner as compared to trials in which they only differed in terms of place of articulation. Overall, it seems that the phonological similarity between the first phoneme of the spoken word and the *unrelated* distractor does influence looking proportions towards the *onset* competitor confirming the hypothesis that even *unrelated* distractors may drive adults' attention during spoken-word recognition in a visual world paradigm. Results from the present experiment therefore emphasise the importance of carefully controlling even seemingly *unrelated* distractors when examining spoken-word recognition using a visual world paradigm with adults.

Furthermore, the present experiment further supports assumptions

made by the FUL account (Lahiri & Reetz, 2010): Not only did the phonological similarity between the first phonemes of the spoken word and the *unrelated* distractor modulate looking proportions towards the *onset* competitor, but also did the order in which these sounds were presented have a significant impact: Participants displayed much faster and higher looking proportions towards the *onset* competitor when the spoken word started with a coronal phoneme and was followed by the image of an *unrelated* distractor that started with a non-coronal phoneme (e.g. *t* - *p*) as compared to the reverse direction. These findings further support the idea that an *unrelated* distractor is only able to successfully deviate attention away from the *onset* competitor if its first phoneme was previously activate through the first phoneme of the spoken word. More specifically, the FUL assumes that coronal phonemes do not activate non-coronal phonemes with the same strength that non-coronal phonemes activate coronal phonemes. In cases where the first phoneme of the spoken word is a non-coronal phoneme, it may therefore already activate the first (coronal) phoneme of the *unrelated* distractor. This increased activation may increase the strength with which the *unrelated* distractor can drive attention away from the *onset* competitor. Looking proportions towards the *onset* competitor may therefore be reduced in such a scenario.

Finally, the present experiment used pseudowords rather than real spoken words since a pilot study using real words in an identical setup did not reveal any phonological *onset* effects. These findings support the

idea from Experiment 6 that using pseudowords might facilitate the detection of small phonological effects in both infants and adults. The reason for this could be that real words might activate a large set of lexical information which may overshadow the rather small phonological effects. Future research investigating phonological competition during spoken-word recognition using a visual world paradigm might therefore consider making use of pseudowords rather than real words.

Chapter 10

Discussion

10.1 Overview of Main Findings

The aim of this thesis was to examine how phonological information mediates visual attention in infants and adults. Experiments made use of the Visual World Paradigm during which participants saw images on a screen and heard phonologically related or unrelated words in order to investigate the time course of processing of phonological information. Looking behaviour was compared between adults and 2-year-old infants. Experiments of this thesis further examined how the amount of time observers were given to look at the images before hearing a spoken word (pre-naming time) and the concept of implicit naming (silent labelling of the images) may modulate observers' processing strategies. Additionally, this thesis examined competition between different types of phonologically related competitors (e.g. *onset* vs. *rhyme* competi-

tors) and how different degrees of phonological similarity may impact *rhyme* effects in both infants and adults. Finally, experiments investigated whether continuous processing models such as TRACE may need to be extended by taking into account the strength of activation between different phonemes depending on the direction in which these phonemes activate each other. Table 10.1 provides an overview of the main methodological choices and results for each of the experiments. The following section will give a more detailed overview of the experimental outcomes of each chapter.

Experiment 1 Experiment 1 was a first attempt at developing a study similar to Allopenna et al. (1998)'s classic adult experiment in 2-year-old infants in order to examine whether looking behaviour in infants may also resemble simulations from continuous processing models such as TRACE (McClelland & Elman, 1986). Results indicated no preference in infants for any type of phonological competitor over unrelated distractors. Using the same setup with adults demonstrated increased looking proportions towards *onset* competitors, however, while there was a trend of significant looking proportions towards *rhyme* competitors, this was not significant. It is possible that the lack of phonological effects in infants and the lack of a *rhyme* effect in adults may stem from direct competition between *onset* and *rhyme* competitors or the relatively short pre-naming phase of only 200ms. Huettig & McQueen (2007) have previously suggested that such short preview of the images may prevent phonological information from guiding language-

Exp.	Adult/ Child	Age	Time	Conditions	Pic.	Non-/ Word	Main Results
1	A	-	200ms	- onset vs. rhyme vs. distractor	4	W	- significant onset effect
							- no significant rhyme effect
1	C	24-30	200ms	- onset vs. rhyme vs. distractor	4	W	- onset effect despite only 200ms preview
2	A	-	200ms	- photograph vs. line drawing	4	W	- no significant phonological effects
3a	C	30	2s	- onset vs. distractor	2	W	- no significant phonological effects
				- rhyme vs. distractor			
				- distractor vs. distractor			
3b	A	-	1s	- onset vs. distractor	2	W	- significant rhyme and onset effects
				- rhyme vs. distractor			- larger rhyme effects in similar condition
				- similar vs. different			
4	A	-	0s	- onset vs. distractor	2	W	- no onset effect
				- rhyme vs. distractor			- smaller rhyme effect than Exp. 3b
5	C	30	6s	- onset vs. rhyme vs. distractor	4	W	- no phonological effects
6	C	30	0s	- rhymes vs. distractor	4	N	- rhyme effects as expected
				- onset vs. rhyme vs. distractor			- no onset effect
				- rhyme close vs. distant			- no difference in rhyme effect for two conditions (rhyme close vs. distant)
7	A	-	0s	- direction for non-/coronal	2	W	- stronger rhyme effect for coronal to non-coronal condition
				- similarity of first phoneme			- larger rhyme effect with increasing similarity of first phoneme
				- similarity of vowels			- smaller rhyme effect if vowel of distractor similar to vowel of spoken word
8	A	-	0s	- direction for non-/coronal	2	N	- looking trajectory influenced by similarity between distractor and spoken word
				- similarity of first phoneme			- stronger onset effect for coronal to non-coronal condition

Table 10.1: Overview of the main methodological choices and results for each of the experiments used for this thesis (participants group: adult/child, age (months); pre-viewing time of images before hearing the spoken word; different conditions tested; number of images in the visual display; use of real words or non-words; main results).

mediated visual attention. Experiment 1, however, demonstrated that 200ms were sufficient to elicit increased fixations towards phonological *onset* competitors contradicting the claims made by Huettig & McQueen (2007).

Experiment 2 Experiment 2 investigated the idea that the lack of phonological effects in Huettig & McQueen (2007) may stem from the fact that the author used line drawings rather than photographs as employed in experiment 1 of this thesis. As Huettig & McQueen (2007) showed in their study, the way information is presented in a visual world paradigm influences the retrieval of phonological, semantic and visual information. It is possible that retrieving such information from line drawings takes longer than retrieval from photographs. When replicating experiment 1 with line drawings, participants did indeed not show significantly increased fixations towards phonologically related competitors over unrelated distractors. This is likely due to the idea that observers take longer to extract information from line drawings than photographs (Davies et al., 1978; Leder, 1996; Rossion & Pourtois, 2004; Tversky & Baratz, 1985). This has important implications for researchers choosing stimuli for studies investigating spoken-word recognition in visual world paradigms.

Experiment 3 The aim of Experiment 3 was to determine whether separating *onset* and *rhyme* competitors would allow for phonological effects to become apparent in infants and for significant *rhyme* effects to be revealed in adults. Furthermore, the pre-naming phase was increased

to 2 seconds for infants and to one second for adults in order to facilitate occurrence of phonological effects. Despite increased pre-naming phase and separation of the *onset* and *rhyme* objects, no phonological effects were discovered in infants. Adults displayed *onset* as well as *rhyme* effects under these conditions suggesting that in Experiment 1, the presence of an *onset* competitor in fact suppressed activation of the *rhyme* competitor. An alternative explanation could have been that the longer pre-naming time in Experiment 3 allowed for *rhyme* effects to become visible. However, results from Experiment 4 (see below) did not support this hypothesis. Finally, in Experiment 3, *Rhyme* effects were larger when the first phoneme of the *rhyme* competitor differed from the spoken phoneme only in terms of voicing as compared to a difference in terms of voicing, place and manner; suggesting that the amount of phonological similarity at the beginning of a word influences phonological competition during spoken-word recognition in adults.

Experiment 4 The aim of Experiment 4 was to determine whether phonological *rhyme* and *onset* effects can be observed in a visual world paradigm when adult participants are not given any time to look at the images before hearing the target word. The design and stimuli were identical to Experiment 3, however, visual stimuli were presented immediately at the offset of the spoken target word, preventing participants from seeing the images before hearing the entire spoken word. Results revealed that there was still a, reduced, *rhyme* effect observable while the overall *onset* effect vanished under these conditions. The findings

suggest that when given time to implicitly name images, listeners might be using a more incremental strategy of processing the auditory input whereas without any prior information on the visual display, they may be using a more global continuous mapping strategy.

Experiment 5 The first few infant experiments conducted for this thesis did not reveal any effects of phonological competition during spoken-word recognition in 2-year olds. This is in contrast with studies such as Swingley et al. (1999) and Chow et al. (2015). Experiment 5 was therefore an attempt to replicate a study by Chow et al. (2015) with the same setup and stimuli. Experiment 5 confirmed findings of early fixations towards *onset* competitors as demonstrated by Chow et al. (2015). However, closer inspection revealed that this apparent *onset* effect was driven by only one particular trial in which the phonological code of the spoken word was embedded within the phonological code of the *onset* competitor ("Look at the *beans*." presented together with the image of a *bee*). Taken together, these results suggest that visual attention in infants is only mediated by phonological competition when the spoken word is embedded within the label of the phonological competitor.

Experiment 6 Experiment 6 explored the hypothesis that using real words in the previous studies may have engaged infants' lexicons in a way that overshadowed any subtle phonological effects. For this experiment, spoken words were therefore replaced with spoken pseudowords and were presented to infants immediately before four images appeared

on the screen. Under these conditions infants displayed increased fixations towards *rhyme* competitors starting approximately 600ms after onset of the visual display. This time course of looking behaviour suggests that 2-year-olds do not simply seem to follow an incremental strategy when processing spoken words but their attention seems to rather be directed by the overall similarity between the words they hear and the phonological code of the objects they are presented with.

Experiment 7 Experiment 7 investigated whether coronal and non-coronal phonemes activate each other with differing strengths depending on the direction of activation. Results revealed that adults were faster looking at a *rhyme* competitor when they heard a spoken word that started with a non-coronal phoneme and saw an image who's label started with a coronal phoneme (e.g. *p* - *t*) as opposed to hearing a word that started with a coronal phoneme and seeing an image with a label that started with a non-coronal phoneme (e.g. *t* - *p*). This confirms predictions made by the Featurally-Underspecified Lexicon approach (Lahiri & Reetz, 2010) and suggests that continuous processing models such as TRACE (McClelland & Elman, 1986) may need to be extended in order to take into account the strength of activation between different phonemes depending on the direction in which these phonemes become activated.

Experiment 8 Experiment 8 tested the hypothesis derived from Experiment 1 that the first phoneme of phonologically unrelated distractors may modulate the strength of *onset* effects. Results showed that

adults' trajectory of fixations on an *onset* competitor were significantly different when the first phoneme of the *unrelated* distractor differed from the first phoneme of the spoken word in terms of place, manner and voicing as compared to trials where the first phonemes only differed in terms of voicing; or trials where they differed only in terms of place of articulation. These findings suggest that phonological information from seemingly unrelated distractors can in fact modulate the strength of phonological competition created by phonologically related competitors. This has important implications for researchers to carefully manipulate seemingly unrelated distractors in a visual world paradigm.

10.2 Strengths and Limitations

The following section will provide an overview of the relative strengths and limitations of the designs, methods and analyses used for this thesis.

10.2.1 Visual World Paradigm

The Visual World Paradigm has frequently been used as a measure of fine-grained competition during spoken-word recognition (Huettig et al., 2011). Unlike priming methods, the VWP is suitable for investigating the time course of competition created by different types of competitors as spoken words unfold. It allows examining at which

point in time during the unfolding of a spoken word, viewers' attention is directed towards different types of objects that are, for instance, phonologically related to the spoken word. Furthermore, as opposed to Inferential Looking Paradigms, using VWP methods ensures that looking proportions for one object are not directly influenced by looking proportions to another object. Presenting viewers with four images on a screen allows for creating a baseline measure (e.g. in the form of unrelated distractors) that is not simply an inverse of looking proportions towards related competitors. Finally, tracking participants' eye movements in a VWP allows making inferences about ongoing cognitive processes without requiring participants to make active responses. This makes it a particularly desirable design for infants who are too young to give responses such as speaking, pressing buttons or pointing at objects.

While the VWP is a good measure of fine-grained competition during spoken-word recognition, recent evidence suggests that complementing measures of looking proportions with measures of pupil dilation may improve sensitivity, especially when conducting studies with 2-year-olds (Angulo-Chavira & Arias-Trejo, 2018). Given the lack of findings in a lot of the infant studies presented in this thesis, employing additional pupil dilation methodologies may have lead to additional insights.

10.2.2 Growth Curve Analysis

The use of VWP methods has enabled researchers to investigate fine-grained competition as it unfolds over time. While in early studies there was a lack of methods to perform rigorous statistics on time course data coming from VWP, the Growth Curve Analysis (GCA) methods based on Mirman et al. (2008) used in this thesis overcome a lot of these early challenges. GCA allows to assess change over time while taking into account individual participant differences as well as variations that might stem from individual trials. This way, effects were only shown significant if they were not due to individual participants behaving very differently from the rest of the groups or individual stimuli eliciting unique behaviour.

10.2.3 Statistical Power

Developmental research, in particular with infants as young as 2 years, comes with a lot of challenges when it comes to designing experiments. While statistical analysis usually requires large amounts of data in order to produce reliable results, obtaining such quantities of data is particularly hard with infants. 2-year-olds tend to get easily extracted, bored and exhausted when performing repetitive tasks. It is for this reason that studies with this age group typically have considerably less trials than adult experiments. With this fact, however, comes the problem of statistical power. In the present thesis, the number of experimental trials for infant experiments ranged from 8 to 27 trials. Together with

infants' naturally high variance in looking behaviour, this setup lead to very low effect sizes and, thus, the experiments presented here are low in power. This has to be taken into consideration when drawing conclusions, in particular, from the null effects observed in most infant experiments presented. It is possible that 2-year-olds do in fact employ adult-like strategies of processing phonological competition in spoken-word recognition but that the designs used for this thesis were not powerful enough in order to be able to detect phonological effects in infants. A lack of significant findings here might simply be due to a lack of statistical power.

10.2.4 Use of Monosyllabic Words

In order to control for stimuli length, the present experiments primarily made use of monosyllabic stimuli. While this ensured that stimuli length did not vary greatly between trials, using only monosyllabic words may have had an impact in the way phonological effects were revealed in both infants and adults. Recent evidence suggests that the use of monosyllabic words may weaken possible *rhyme* effects while increasing *onset* effects. Simmons (2017), for instance, suggest that children as young as 3-4 years already demonstrate looking behaviour towards *onset* and *rhyme* competitors which resembles looking behaviour of adults when presented with the same stimuli. However, the authors found that *rhyme* effects tended to be weaker and *onset* effects larger when monosyllabic words were used. These findings would explain why

in Experiment 1 which used monosyllabic words in direct competition to each other, *onset* effects were observable in adults whereas *rhyme* effects were not significant. It is possible that using longer words for Experiment 1 would have lead to reduced *onset* effects and significant *rhyme* effects. The rationale behind this is, that the phonological overlap between the rhyme and the spoken word is relatively small when using monosyllabic words which may lead to processing strategies placing more focus on the first phoneme rather than the overall similarity between spoken word and rhyme. Such strategies would facilitate activations of *onset* competitors rather than *rhyme* competitors.

10.2.5 Generalisability

Finally, caution should be taken when generalising the present findings to a more general understanding of spoken-word recognition. In particular, Experiment 5 demonstrated how an individual trial may have a large impact on overall experimental observations. This observation becomes even more important when considering the small number of trials that were used in many of the present infant experiments as compared to standard adult eye-tracking experiments. One strength of the GCA analysis employed throughout this thesis, however, is the possibility of factoring in the impact of individual trials on the overall experimental results when conducting statistical analysis (Mirman et al., 2008). It is for this reason that in Experiment 5, no statistically significant *onset* effects were found even though initial visual inspection

of the time course of looking proportions may have suggested a strong *onset* effect. While this type of analysis ensured that individual stimuli variances were taken into account, caution should still be taken when generalising the present findings, particularly to setups where longer non-monosyllabic words are processed.

The conclusions presented in the following general discussion should be considered taking into account the limitations described in the above section.

10.3 Spoken-Word Recognition in Infants

The findings of this thesis do not allow for any definite conclusions regarding the question whether infants use continuous or incremental mapping strategies when encoding spoken words. In all experiments of this thesis that made use of real spoken words, infants showed no preference for phonologically related competitors over unrelated distractors. It seems that lexical, visual and semantic information plays a much more important role in attracting infants' attention than does phonological information. This may be due to 2-year-old infants having greater conceptual and semantic knowledge as compared to phonological knowledge. Infants acquire conceptual information at a very early age before they even know how to produce sounds for such concepts. For instance, 3-month-olds are already capable of categorising objects based on their perceptual features (Eimas & Quinn, 1994; Eimas et

al., 1994) and it has been suggested that infants make use of semantic knowledge in order to acquire phonological knowledge (Pinker & Levin, 1991). Infants' lexicons might therefore still be much more organised around conceptual and semantic knowledge than phonological knowledge as compared to adults who seem to make use of visual, semantic and phonological knowledge during spoken-word recognition (Huettig & McQueen, 2007). This suggestion is also in line with findings by Chow et al. (2015) who showed that while 2-year-olds are sensitive to both semantic and phonological information, their visual attention seems to be modulated more by the first than the latter.

When presented with pseudowords, infants' looking behaviour indicated increased looking proportions towards the *rhyme* competitor starting approximately 600ms after onset of the visual display but no increased looking proportions towards *onset* competitors. These findings indicate that 2-year-olds do not place great importance on the onset of spoken words but their attention seems to rather be directed by the overall similarity between the words they hear and the phonological code of the objects they are presented with. This may be interpreted as evidence for infants displaying more continuous mapping processes such as described in the TRACE model (McClelland & Elman, 1986) rather than incremental mapping processing described by the Cohort model (Marslen-Wilson, 1987). However, unlike predicted by TRACE, infants did not display an early increase in looking proportions towards *onset* competitors as has been observed in adults. Furthermore, results

from experiment 5 show that, unlike adults, infants' strategy of processing spoken words does not seem to depend on how much time they are given to implicitly name images before hearing the spoken word. Infants displayed preference for *rhyme* competitors even when they were given no time to inspect objects before hearing a spoken pseudoword.

10.4 Implicit Naming and the Pre-Naming Phase

Unlike findings from Huettig & McQueen (2007), we found that a previewing time of 200ms is long enough for adults to be sensitive to phonological *onset* competitors. When presented with four images for 200ms before hearing a target word, adults showed early increased fixations towards competitors that had the same first phoneme as the spoken word.

These findings have important implications for our understanding of the locus of word-picture matching during spoken-word recognition. One account of word-picture matching, the implicit naming account suggests that participants implicitly label all images they are presented with and then match these generated phonological codes to the incoming auditory input. Observers may then, for example, fixate more on the picture of a pen when hearing the word "pear" due to the partial match in the beginning of these two words. This account suggests that under circumstances in which observers do not have enough time to label the

images they are presented with before hearing the target word, they should not display a preference for phonologically related competitors since the incoming auditory input cannot be matched to previously extracted phonological codes derived from the images. The findings of this thesis that observers preferentially fixate on *onset* competitors over unrelated distracted even with a pre-viewing time of 200ms which does not allow implicit labelling of all images (Huettig & McQueen, 2007) therefore contradicts the implicit naming account.

An alternative process of matching the spoken word and the pictures could be that by extracting the phonological representation of the auditory input, various phonological neighbours are also activated together with their respective semantic and visual representations. Therefore, when hearing the word "pear", its phonological neighbour "pen" might also become activated, increasing looking proportions to the picture of a pen.

When entirely removing the pre-viewing time of the images before hearing the spoken target word, adult participants did not spend more time looking at *onset* competitors than unrelated distractors. Looking proportions to *rhyme* competitors were still increased as compared to unrelated distractors, albeit lower than with longer pre-viewing times. This suggests that adults display a preference for phonologically related competitors even when they are given no pre-view of the images before they hear a spoken word. However, their processing strategies seem to be modulated by the amount of pre-viewing time they are given -

particularly impacting preference for the *onset* competitor. When presented with the images before hearing the spoken word, observers seem to make use of more incremental processing strategies focusing on the first phoneme of words. However, without any pre-viewing time, observers seem to use more continuous processing strategies taking into account the overall similarity of words. This is why, when entirely removing the pre-viewing phase, *onset* effects are not observed any more. In such cases, the phonological representation of the auditory input has already been extracted by the time participants see the visual display. This phonological representation then activates all phonological neighbours together with their semantic and visual representations. Since *onset* competitors do not share a lot of phonological similarities with the spoken word, such lexical neighbour are not activated enough to elicit fixations. *Rhyme* competitors, on the other hand, are close lexical neighbours to the spoken word and, thus, evoke higher looking proportions under such conditions.

The findings that *onset* effects were still visible in experiment 1 with a pre-naming time as short as 200ms might be due to the possibility that 200ms might have been enough to activate the beginning of the phonological codes for the images displayed on the screen. This way, the first phonemes of the phonological code for each of the images might have been available by the time participants heard the spoken word which would explain why *onset* effects were observable with a pre-naming time as short as 200ms but not when entirely removing the

pre-naming phase.

Taken together, these findings suggest that adults make use of both incremental as well as continuous mapping strategies when appropriate. Consequently, in order to fully understand the processes underlying spoken-word recognition in adults, one has to combine theories of spoken-word recognition such as the TRACE model with picture-word matching strategies such as the concept of implicit naming.

10.5 Different Types of Phonological Competitors

10.5.1 Onset vs. Rhyme

Experiment 1 demonstrated that in cases where *onset* competitors were presented together with *rhyme* competitors, the *onset* competitors seemed to win the competition for attention. Under such conditions, looking proportions towards *onset* competitors were increased while they did not reach significance for *rhyme* competitors. However, when separating the two types of competitors (Experiment 3), a clear preference for *rhyme* competitors over unrelated distractors could be found. These findings are in line with simulations from the TRACE model (McClelland & Elman, 1986) which predict that in an alternative forced-choice scenario, multiple phonological distractors compete with each other. Thus, introducing an additional phonological competitor

will reduce looking proportions to the remaining competitors. While the present results provide further support for continuous processing models such as TRACE they also highlight the special status of the beginning of spoken words during auditory word recognition (Connine et al., 1993). Despite *onset* competitors having much smaller overlap with the spoken word than *rhyme* competitors, they seem to win the competition for attention due to the great importance adults place on the first phoneme of words.

10.5.2 Sub-Phonemic Features

The degree to which phonological competitors can mediate visual attention does not only seem to depend on the degree of phonological overlap with the spoken word but also on sub-phonemic differences (Altvater-Mackensen & Mani, 2015). Findings from this thesis demonstrate that the more similar the first phoneme of a *rhyme* competitor is to the first phoneme of a spoken word, the more observers fixate on the *rhyme* competitor. This is in line with previous research which has shown that adults spend more time looking at an object when its first phoneme differs from the first phoneme of the spoken word only in one feature as compared to a difference in two features (Mitterer, 2011).

The present findings yield further support for interactive activation models such as TRACE (McClelland & Elman, 1986). Such models suggest that during spoken-word recognition, the auditory input leads to activation of features at the feature level which then leads to acti-

vation of phonemes that are congruent with the input. Phonemes are activated through excitatory and inhibitory connections and the more similar two phonemes are the more likely they are to activate each other.

While we did find a strong mediation of visual attention by sub-phonemic features in adults, 2-year-old infants did not display the same pattern. This is in contrast with previous research which has suggested that *rhyme* priming effects 2-year-olds vary linearly with the amount of sub-phonemic feature overlap (Altvater-Mackensen & Mani, 2015) and that 19-month-old infants already display a graded sensitivity to sub-segmental details when presented with mispronunciations (White & Morgan, 2008). Future research may be necessary in order to determine under which conditions infants' visual attention may be mediated by sub-phonemic features.

10.5.3 Importance of Unrelated Distractors

Previous research into phonological competition during spoken-word recognition has mainly focussed on competition created by different types of phonological competitors. No research so far has attempted to explicitly modulate the phonological competition created by *unrelated* distractors. Post-hoc analysis from Experiment 1 suggested that the phonological similarity between the first phoneme of the *rhyme* competitor and the spoken word may modulate fixations towards the *onset* competitor. It may therefore be the case that the first phonemes of

all competitors in a visual display compete for the observer's attention and that even *unrelated* distractors may drive attention away from a phonologically related competitor if their first phoneme is very similar to the spoken word. Experiment 8 explicitly tested this hypothesis and revealed that this similarity, indeed, modulated the trajectory of looking proportions towards the *onset* competitor. These findings provide further support for interactive-activation models such as TRACE (McClelland & Elman, 1986) whereby different words compete with each other through inhibitory and excitatory connections until one is selected. The more similar the beginning of an unrelated distractor sounds to the beginning of the spoken word, the more competition it can create directing attention away from the phonological competitor. Finally, these findings have important implications for researchers designing studies to investigate spoken-word recognition. More importance needs to be placed on carefully manipulating seemingly unrelated distractors since even subtle similarities seem to drive language-mediated visual attention.

10.6 Line Drawings vs. Photographs

Findings from Experiment 2 provide evidence that recognition of line drawings takes significantly longer than recognition of photographs. While we were able to demonstrate a strong preference for *onset* competitors when using photographs in Experiment 1 even with a short pre-viewing time of 200ms, this preference disappeared when using line

drawings in experiment 2. The difference in results is likely to be due to the longer time it takes observers to extract information from line drawings as compared to real photographs and is in accordance with findings by previous studies comparing recognition of photographs and line drawings (Davies et al., 1978; Leder, 1996; Rossion & Pourtois, 2004; Tversky & Baratz, 1985). It seems that details provided by a photograph, such as colour and its general greater resemblance with real-life objects may facilitate object recognition (Davies et al., 1978). As stated previously, it may be the case that 200ms might be enough for observers to activate the beginning of the phonological code for the images presented when these are real photographs. This partial implicit naming may, however, take longer when using line drawings due to the increased processing time associated with the recognition of line drawings.

The present findings provide evidence for image-based theories of object recognition (Tarr & Bülthoff, 1998) which propose that observers process objects as a whole and that adding texture and colour information may aid object recognition. They contradict edge-based theories of object recognition (Grossberg & Mingolla, 1985; Marr, 1982; Marr & Nishihara, 1978) which suggest that shape is the main contributor to object recognition and that adding surface or texture information does not facilitate recognition. Bearing image-based theories of object recognition in mind, future research should carefully consider which type of stimuli to use depending on the research questions posed and caution

should be taken when comparing studies that made use of different types of object representations.

10.7 The Featurally-Underspecified Lexicon

The present findings provide support for the Featurally-Underspecified Lexicon account (Lahiri & Reetz, 2010) and suggest that continuous processing models such as TRACE (McClelland & Elman, 1986) may need to be extended in order to take into account the direction with which different phonemes activate each other. The TRACE model (McClelland & Elman, 1986) proposes that upon hearing spoken words, various lexical candidates are activated in parallel and compete with each other through inhibitory and excitatory connections. The model suggests that activation of one phoneme also leads to activation of similarly sounding phonemes through these excitatory connections. No claims are, however, made regarding whether these connections differ in strength depending on their connection. It is rather assumed that one phoneme will activate another one with the same strength as an activation in the opposite direction.

The FUL, however, suggests that the strength of these activations differ in particular regarding coronal/non-coronal phonemes. While coronal phonemes are produced using the flexible front part of the tongue, non-coronals are produced without raising this part of the tongue. The

FUL proposes that there is an asymmetry in adults' representations of these coronal and non-coronal features. More specifically, it claims that while non-coronals can activate other non-coronals as well as coronals, coronals themselves are only able to activate other coronals. This is due to the assumption that coronals are underspecified according to the FUL. The FUL therefore predicts that observers should be faster looking at a *rhyme* competitor when the spoken word starts with a non-coronal phoneme and the *rhyme* object starts with a coronal phoneme as opposed to reversed trials. The rationale behind this is the idea that coronals may already have been activated through excitatory connections when preceded by a non-coronal target word, thereby facilitating object recognition. The present results did indeed show faster looking towards the *rhyme* competitor when the spoken word started with a non-coronal phoneme and the *rhyme* object started with a coronal phoneme confirming the proposition that continuous processing models such as TRACE may need to be extended to take into account the direction of activation between different phonemes.

10.8 Concluding Remarks

Taken together, this thesis has demonstrated that during spoken-word recognition, adults make use of continuous processing strategies resembling simulations from continuous processing models such as TRACE (McClelland & Elman, 1986). No final conclusions could be made for 2-year-olds' processing strategies, however, increased looking proportions

towards *rhyme* competitors but not *onset* competitors when using pseudowords seem to suggest that infants do not place great importance on the onset of spoken words but their attention seems to rather be directed by the overall similarity between words. This may be interpreted as evidence for infants displaying more continuous mapping processes rather than incremental mapping processes described by the Cohort model (Marslen-Wilson, 1987). The amount of time adults are given to inspect images before hearing a spoken word seems to modulate their processing strategies through mechanisms of implicit naming. Contradictory to findings by Huettig & McQueen (2007), results of this thesis demonstrate that adults' visual attention seems to be modulated by phonological information even with a pre-viewing time as short as 200ms. This time might be enough to allow adults to extract the beginning of the phonological code for the images displayed before hearing the spoken word. This process of implicit naming may, however, take longer when presenting adults with line drawings rather than real photographs of the objects leading to a lack of phonological effects when allowing adults only 200ms to inspect line drawings before hearing the spoken word. When entirely removing the pre-naming phase, phonological onset effects seem to disappear while phonological rhyme effects are reduced. These findings seem to suggest that implicit naming and the amount of time adults are given to inspect and potentially implicitly name images before hearing a spoken word has an impact on the processing strategies employed: when given a pre-naming phase, adults seem to make use of processing strategies focusing on the first

phoneme of words whereas without any pre-naming time, they seem to rely more on processing strategies taking into account the overall similarity of words.

Findings from this thesis further revealed that phonological effects during spoken-word recognition in 2-year-old infants may become more apparent when making use of pseudowords rather than real words. This may be due to real words activating infants' lexicons in a way that may overshadow more subtle phonological effects.

Furthermore, the present results provide first evidence for the idea that phonological information from seemingly unrelated distractors can modulate adults' visual attention during spoken-word recognition. Looking behaviour towards onset competitors seemed to be modulated by the degree of similarity between the first phoneme of the phonologically unrelated distractor and the first phoneme of the spoken word.

Finally, this thesis provides support for the Featurally-Underspecified Lexicon account (Lahiri & Reetz, 2010) which suggests that different coronal and non-coronal phonemes do not activate each other with the same strength. The FUL claims that while non-coronals can activate other non-coronals as well as coronals, coronals themselves are only able to activate other coronals. Since the present findings provide evidence for this suggestion, continuous processing model such as TRACE (McClelland & Elman, 1986) may need to be extended to take into account the direction with which different phonemes activate each other.

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Appendix A

Experiments 1 & 2

	Target	Onset	Rhyme	Unrelated 1	Unrelated 2	Condition
Block 0.1	boot	boot	mouth	stairs	key	present
	glass	glass	bird	slide	tongue	present
Block 1.1	owl	owl	bread	ear	stone	present
	star	sock	car	door	pen	absent
	bed	bed	lamp	nose	milk	present
	house	hand	mouse	spoon	cot	absent
	cake	cake	sheep	bowl	arm	present
Block 2.1	plate	plate	cow	swing	bread	present
	frog	foot	dog	truck	boat	absent
	book	book	fish	plane	ear	present
	cat	cup	hat	chair	door	absent
	pig	pig	box	train	eye	present
Block 3.1	fork	fork	horse	brush	stone	present
	trees	truck	cheese	bus	cot	absent
	tooth	tooth	dress	bird	stairs	present
	hair	hat	chair	mouse	cup	absent
	peas	peas	watch	sheep	box	present
Block 4.1	blocks	blocks	mouth	lamp	cow	present
	boat	bear	coat	cheese	foot	absent
	juice	juice	fish	stairs	arm	present
	pup	pear	cup	bus	sock	absent
	doll	doll	bird	nose	swing	present
Block 5.1	toast	toast	horse	slide	eye	present
	moon	mouse	spoon	hand	ship	absent
	soap	soap	lamp	fish	train	present
	clock	coat	sock	bear	pen	absent
	toes	toes	plane	bread	key	present
Block 6.1	egg	egg	cow	nose	bowl	present
	chip	chair	ship	foot	dog	absent
	bag	bag	milk	tongue	stone	present
	bear	boat	pear	car	shoes	absent
	sink	sink	mouth	box	horse	present
Block 7.1	leg	leg	slide	brush	milk	present
	duck	dog	truck	coat	ship	absent
	shirt	shirt	bowl	train	ear	present
	sand	spoon	hand	bus	shoes	absent
	bee	bee	swing	plane	eye	present
Block 8.1	ball	ball	key	arm	sheep	present
	coat	car	boat	pear	door	absent
	bath	bath	tongue	dress	watch	present
	chair	cheese	bear	hat	pen	absent

Table A.1: Experiments 1 & 2 - Trial List 1

	Target	Onset	Rhyme	Unrelated 1	Unrelated 2	Condition
Block 0.2	toast	toast	horse	slide	eye	present
	toes	toes	plane	bread	key	present
Block 1.2	peas	peas	watch	sheep	box	present
	bear	boat	pear	car	shoes	absent
	soap	soap	lamp	fish	train	present
	moon	mouse	spoon	hand	ship	absent
	glass	glass	bird	slide	tongue	present
Block 2.2	cake	cake	sheep	bowl	arm	present
	cat	cup	hat	chair	door	absent
	blocks	blocks	mouth	lamp	cow	present
	sand	spoon	hand	bus	shoes	absent
	pig	pig	box	train	eye	present
Block 3.2	bag	bag	milk	tongue	stone	present
	boat	bear	coat	cheese	pen	absent
	egg	egg	cow	nose	bowl	present
	star	sock	car	door	foot	absent
	juice	juice	fish	stairs	arm	present
Block 4.2	sink	sink	mouth	box	horse	present
	house	hand	mouse	spoon	cot	absent
	bee	bee	swing	plane	eye	present
	clock	coat	sock	bear	pen	absent
	ball	ball	key	arm	sheep	present
Block 5.2	shirt	shirt	bowl	train	ear	present
	trees	truck	cheese	bus	cot	absent
	bed	bed	lamp	nose	milk	present
	chip	chair	ship	foot	dog	absent
	plate	plate	cow	swing	bread	present
Block 6.2	tooth	tooth	dress	bird	stairs	present
	pup	pear	cup	bus	sock	absent
	leg	leg	slide	brush	milk	present
	frog	foot	dog	truck	boat	absent
	owl	owl	bread	ear	stone	present
Block 7.2	boot	boot	mouth	stairs	key	present
	chair	cheese	bear	hat	pen	absent
	doll	doll	bird	nose	swing	present
	duck	dog	truck	coat	ship	absent
	bath	bath	tongue	dress	watch	present
Block 8.2	book	book	fish	plane	ear	present
	hair	hat	chair	mouse	cup	absent
	fork	fork	horse	brush	stone	present
	coat	car	boat	pear	door	absent

Table A.2: Experiments 1 & 2 - Trial List 2

	Target	Onset	Rhyme	Unrelated 1	Unrelated 2	Condition
Block 0.3	shirt	shirt	bowl	train	ear	present
	bath	bath	tongue	dress	watch	present
Block 1.3	leg	leg	slide	brush	milk	present
	clock	coat	sock	bear	pen	absent
	toes	toes	plane	bread	key	present
	trees	truck	cheese	bus	cot	absent
	blocks	blocks	mouth	lamp	cow	present
Block 2.3	fork	fork	horse	brush	stone	present
	cat	cup	hat	chair	door	absent
	juice	juice	fish	stairs	arm	present
	boat	bear	coat	cheese	pen	absent
	peas	peas	watch	sheep	box	present
Block 3.3	bed	bed	lamp	nose	milk	present
	moon	mouse	spoon	hand	ship	absent
	ball	ball	key	arm	sheep	present
	chip	chair	ship	foot	dog	absent
	glass	glass	bird	slide	tongue	present
Block 4.3	bee	bee	swing	plane	eye	present
	bear	boat	pear	car	shoes	absent
	boot	boot	mouth	stairs	key	present
	house	hand	mouse	spoon	cot	absent
	bag	bag	milk	tongue	stone	present
Block 5.3	book	book	fish	plane	ear	present
	frog	foot	dog	truck	boat	absent
	pig	pig	box	train	eye	present
	pup	pear	cup	bus	sock	absent
	egg	egg	cow	nose	bowl	present
Block 6.3	owl	owl	bread	ear	stone	present
	duck	dog	truck	coat	ship	absent
	toast	toast	horse	slide	eye	present
	hair	hat	chair	mouse	cup	absent
	soap	soap	lamp	fish	train	present
Block 7.3	plate	plate	cow	swing	bread	present
	star	sock	car	door	foot	absent
	tooth	tooth	dress	bird	stairs	present
	chair	cheese	bear	hat	pen	absent
	cake	cake	sheep	bowl	arm	present
Block 8.3	sink	sink	mouth	box	horse	present
	coat	car	boat	pear	door	absent
	doll	doll	bird	nose	swing	present
	sand	spoon	hand	bus	shoes	absent

Table A.3: Experiments 1 & 2 - Trial List 3

	Target	Onset	Rhyme	Unrelated 1	Unrelated 2	Condition
Block 0.4	plate	plate	cow	swing	bread	present
	cake	cake	sheep	bowl	arm	present
Block 1.4	fork	fork	horse	brush	stone	present
	trees	truck	cheese	bus	cot	absent
	bee	bee	swing	plane	eye	present
	cat	cup	hat	chair	door	absent
	shirt	shirt	bowl	train	ear	present
Block 2.4	bag	bag	milk	tongue	stone	present
	frog	foot	dog	truck	boat	absent
	blocks	blocks	mouth	lamp	cow	present
	star	sock	car	door	foot	absent
	toast	toast	horse	slide	eye	present
Block 3.4	bath	bath	tongue	dress	watch	present
	moon	mouse	spoon	hand	ship	absent
	egg	egg	cow	nose	bowl	present
	bear	boat	pear	car	shoes	absent
	boot	boot	mouth	stairs	key	present
Block 4.4	owl	owl	bread	ear	stone	present
	duck	dog	truck	coat	ship	absent
	doll	doll	bird	nose	swing	present
	house	hand	mouse	spoon	cot	absent
	sink	sink	mouth	box	horse	present
Block 5.4	book	book	fish	plane	ear	present
	coat	car	boat	pear	door	absent
	glass	glass	bird	slide	tongue	present
	hair	hat	chair	mouse	cup	absent
	pig	pig	box	train	eye	present
Block 6.4	toes	toes	plane	bread	key	present
	clock	coat	sock	bear	pen	absent
	juice	juice	fish	stairs	arm	present
	chip	chair	ship	foot	dog	absent
	leg	leg	slide	brush	milk	present
Block 7.4	peas	peas	watch	sheep	box	present
	boat	bear	coat	cheese	pen	absent
	soap	soap	lamp	fish	train	present
	sand	spoon	hand	bus	shoes	absent
ball	ball	key	arm	sheep	present	
Block 8.4	tooth	tooth	dress	bird	stairs	present
	chair	cheese	bear	hat	pen	absent
	bed	bed	lamp	nose	milk	present
	pup	pear	cup	bus	sock	absent

Table A.4: Experiments 1 & 2 - Trial List 4



Figure A.1: Line drawing images used for target absent trials in Experiment 2.

Target	**Rhyme**	***Score***	**Feature differences**
house	mouse	8	difference in manner (obstruent to sonorant), place (dorsal to labial), and voicing
moon	spoon	9	onset cluster
cat	hat	4	difference in manner (obstruent to obstruent) and place (non-coronal to non-coronal)
hair	chair	5	difference in manner (obstruent to obstruent) and place (non-coronal to coronal)
chair	bear	7	difference in manner (obstruent to obstruent), place (coronal to non-coronal) and voicing
boat	coat	6	difference in place (labial to dorsal) and voicing
coat	boat	6	difference in place (dorsal to labial) and voicing
bear	pear	1	difference in voicing
clock	sock	9	onset cluster
star	car	9	onset cluster
frog	dog	9	onset cluster
duck	truck	9	onset cluster
sand	hand	2	difference in place (coronal to non-coronal)
pup	cup	3	difference in place (labial to dorsal)
trees	cheese	9	onset cluster
chip	ship	1	difference in manner (obstruent to obstruent)

Table A.5: Overview of *Phon Scores* for each experimental trial.

Appendix B

Experiments 3 & 4

Target	Phonological Competitor	Unrelated Distractor	Condition
wall	ball (R)	bear	absent
head	car (U)	cheese	absent
sand	sock (O)	hair	absent
mouse	pillow (U)	cup	absent
boy	boy	lamp	present
mouse	house (R)	hat	absent
comb	comb	face	present
chair	cheese (O)	hand	absent
boy	lamp	boy	present
sand	hand (R)	hair	absent
parrot	moon (U)	cookie	absent
lamp	lamp	boy	present
fish	bib	fish	present
sand	pillow (U)	cup	absent
parrot	carrot (R)	cookie	absent
comb	face	comb	present
wall	cookie (U)	car	absent
girl	sink	girl	present
cat	car (O)	house	absent
lamp	boy	lamp	present
girl	sink	girl	present
cat	pen (U)	moon	absent
door	door	nail	present
cat	hat (R)	house	absent
bib	fish	bib	present
chair	watch (U)	sock	absent
nail	door	nail	present
fish	bib	fish	present
nail	nail	door	present
coat	pen (U)	cheese	absent
sink	sink	girl	present
head	house (O)	boat	absent
door	nail	door	present
coat	boat (R)	bed	absent
wall	watch (O)	bear	absent
head	bed (R)	boat	absent
sink	sink	girl	present
book	goose	book	present
coat	cup (O)	bed	absent
goose	book	goose	present
pear	pen (O)	ball	absent
chair	hair (R)	hand	absent
parrot	pillow (O)	cookie	absent
face	comb	face	present
bib	fish	bib	present
book	goose	book	present
mouse	moon (O)	hat	absent
pear	watch (U)	sock	absent
face	comb	face	present
pear	bear (R)	ball	absent
goose	goose	book	present

Table B.1: Experiment 3 - Example Trial List Infants

Target	Phonological Competitor	Unrelated Distractor	Condition	Similar/Different
whale	whale	box	present	-
girl	girl	bread	present	-
shirt	shirt	book	present	-
cot	milk	cot	present	-
stone	boy	stone	present	-
bird	jeep	bird	present	-
dress	dress	sword	present	-
bell	bus (O)	ship	absent	-
train	coin	train	present	-
knot	pot (R)	pine	absent	different
milk	cot	milk	present	-
bread	sink	bread	present	-
phone	phone	shard	present	-
face	boot	face	present	-
train	rake	train	present	-
sherd	wool	sherd	present	-
head	bed (R)	boat	absent	-
jug	jug	horse	present	-
head	house (O)	boat	absent	-
sherd	phone	sherd	present	-
sword	hoof	sword	present	-
toes	rose (R)	ring	absent	different
coin	coin	rake	present	-
coil	coil	horse	present	-
phone	phone	wool	present	-
moose	whip	moose	present	-
goose	goose	book	present	-
tooth	tooth	cot	present	-
pole	mole (R)	map	absent	different
beer	bus (O)	dart	absent	-
hoof	hoof	dress	present	-
fish	fish	leg	present	-
mouse	moon (O)	hat	absent	-
milk	tooth	milk	present	-
hoof	sword	hoof	present	-
pear	pen (O)	ball	absent	-
beach	peach (R)	pig	absent	similar
lamb	nail	lamb	present	-
heart	horn (O)	duck	absent	-
wool	wool	shard	present	-
cap	cake (O)	mole	absent	-
whale	whale	scythe	present	-
pole	peach (O)	map	absent	-
book	goose	book	present	-
wall	watch (O)	bear	absent	-
sink	girl	sink	present	-
chin	bin (R)	bike	absent	different
tooth	milk	tooth	present	-
pear	bear (R)	ball	absent	-

Target	Phonological Competitor	Unrelated Distractor	Condition	Similar/Different
wool	wool	phone	present	-
coil	coil	jug	present	-
lamb	door	lamb	present	-
horse	jug	horse	present	-
jeep	lime	jeep	present	-
nurse	knight (O)	peas	absent	-
goose	goose	shirt	present	-
moose	key	moose	present	-
light	leaf (O)	nose	absent	-
coat	cup (O)	bed	absent	-
heart	dart (R)	duck	absent	different
boot	face	boot	present	-
door	nail	door	present	-
bread	girl	bread	present	-
shirt	shirt	goose	present	-
key	moose	key	present	-
chip	ship (R)	shoe	absent	similar
bird	lime	bird	present	-
corn	horn (R)	hook	absent	similar
coin	coin	train	present	-
chair	hair (R)	hand	absent	-
jug	jug	coil	present	-
parrot	carrot (R)	cookie	absent	-
lime	lime	bird	present	-
bell	shell (R)	ship	absent	different
tail	sail (R)	seat	absent	similar
boy	stone	boy	present	-
comb	comb	face	present	-
chair	cheese (O)	hand	absent	-
rake	coin	rake	present	-
sand	hand (R)	hair	absent	-
lamp	boy	lamp	present	-
door	lamb	door	present	-
bib	fish	bib	present	-
whip	key	whip	present	-
cap	map (R)	mole	absent	different
knot	nose (O)	pine	absent	-
chip	church (O)	shoe	absent	-
fig	pig (R)	pipe	absent	similar
comb	comb	boot	present	-
farm	palm (R)	pot	absent	similar
box	whale	box	present	-
parrot	pillow (O)	cookie	absent	-
face	face	comb	present	-
mouse	house (R)	hat	absent	-
jeep	bird	jeep	present	-
nurse	purse (R)	peas	absent	different
wall	ball (R)	bear	absent	-
lime	jeep	lime	present	-

Target	Phonological Competitor	Unrelated Distractor	Condition	Similar/Different
sink	sink	bread	present	-
cook	cow (O)	hedge	absent	-
girl	girl	sink	present	-
tail	torch (O)	seat	absent	-
box	box	scythe	present	-
lamp	lamp	stone	present	-
lamp	lamp	stone	present	-
farm	fork (O)	pot	absent	-
book	shirt	book	present	-
corn	cake (O)	hook	absent	-
cot	cot	tooth	present	-
fig	foot (O)	pipe	absent	-
cat	car (O)	house	absent	-
sword	dress	sword	present	-
stone	lamp	stone	present	-
cook	hook (R)	hedge	absent	similar
wig	wave (O)	pan	absent	-
coat	boat (R)	bed	absent	-
chin	church (O)	bike	absent	-
dress	hoof	dress	present	-
whip	moose	whip	present	-
bib	leg	bib	present	-
rake	rake	train	present	-
wig	pig (R)	pan	absent	different
scythe	scythe	box	present	-
toes	torch (O)	ring	absent	-
cat	hat (R)	house	absent	-
sand	sock (O)	hair	absent	-
nail	nail	door	present	-
light	knight (R)	nose	absent	similar
pin	purse (O)	bath	absent	-
nail	nail	lamb	present	-
beach	bike (O)	pig	absent	-
meat	mole (O)	soap	absent	-
pin	bin (R)	bath	absent	similar
meat	seat (R)	soap	absent	different
scythe	whale	scythe	present	-
leg	leg	fish	present	-
key	key	whip	present	-
boot	boot	comb	present	-
horse	horse	coil	present	-
fish	fish	bib	present	-
beer	deer (R)	dart	absent	similar
leg	bib	leg	present	-
boy	boy	lamp	present	-

Table B.2: Experiments 3+4 - Example Trial List Adults

Appendix C

Experiment 5

	Target	Onset	Rhyme	Unrelated 1	Unrelated 2	Condition
Block 0.1	cup	cup	pig	train	soap	present
	digger	digger	TV	bunny	cheese	present
Block 1.1	bath	bath	spade	orange	cow	present
	pear	pen	chair	fish	swing	absent
	boat	bowl	coat	tree	door	absent
Block 2.1	table	table	bicycle	sandwich	chicken	present
	bag	ball	flag	horse	juice	absent
	duck	dummy	truck	sofa	shoes	absent
Block 3.1	keys	keys	tiger	pasta	aeroplane	present
	head	helicopter	bed	cake	dress	absent
	wall	watch	doll	towel	strawberry	absent
Block 4.1	fork	fork	window	nappy	bus	present
	cat	carrot	hat	flower	blocks	absent
	beans	bee	jeans	slide	car	absent

Table C.1: Experiment 5 - Trial List 1

	Target	Onset	Rhyme	Unrelated 1	Unrelated 2	Condition
Block 0.2	cup	cup	pig	train	soap	present
	digger	digger	TV	bunny	cheese	present
Block 1.2	table	table	bicycle	sandwich	chicken	present
	bag	ball	flag	horse	juice	absent
	duck	dummy	truck	sofa	shoes	absent
Block 2.2	keys	keys	tiger	pasta	aeroplane	present
	head	helicopter	bed	cake	dress	absent
	wall	watch	doll	towel	strawberry	absent
Block 3.2	fork	fork	window	nappy	bus	present
	cat	carrot	hat	flower	blocks	absent
	beans	bee	jeans	slide	car	absent
Block 4.2	bath	bath	spade	orange	cow	present
	pear	pen	chair	fish	swing	absent
	boat	bowl	coat	tree	door	absent

Table C.2: Experiment 5 - Trial List 2

	Target	Onset	Rhyme	Unrelated 1	Unrelated 2	Condition
Block 0.3	cup	cup	pig	train	soap	present
	digger	digger	TV	bunny	cheese	present
Block 1.3	keys	keys	tiger	pasta	aeroplane	present
	head	helicopter	bed	cake	dress	absent
	wall	watch	doll	towel	strawberry	absent
Block 2.3	fork	fork	window	nappy	bus	present
	cat	carrot	hat	flower	blocks	absent
	beans	bee	jeans	slide	car	absent
Block 3.3	bath	bath	spade	orange	cow	present
	pear	pen	chair	fish	swing	absent
	boat	bowl	coat	tree	door	absent
Block 4.3	table	table	bicycle	sandwich	chicken	present
	bag	ball	flag	horse	juice	absent
	duck	dummy	truck	sofa	shoes	absent

Table C.3: Experiment 5 - Trial List 3

	Target	Onset	Rhyme	Unrelated 1	Unrelated 2	Condition
Block 0.4	cup	cup	pig	train	soap	present
	digger	digger	TV	bunny	cheese	present
Block 1.4	fork	fork	window	nappy	bus	present
	cat	carrot	hat	flower	blocks	absent
	beans	bee	jeans	slide	car	absent
Block 2.4	bath	bath	spade	orange	cow	present
	pear	pen	chair	fish	swing	absent
	boat	bowl	coat	tree	door	absent
Block 3.4	table	table	bicycle	sandwich	chicken	present
	bag	ball	flag	horse	juice	absent
	duck	dummy	truck	sofa	shoes	absent
Block 4.4	keys	keys	tiger	pasta	aeroplane	present
	head	helicopter	bed	cake	dress	absent
	wall	watch	doll	towel	strawberry	absent

Table C.4: Experiment 5 - Trial List 4

Appendix D

Experiment 6

Target	Rhyme	Unrelated 1	Unrelated 2	Unrelated 3/ Onset	Type	Condition
cat	cat	fish	lemon	radio	present	
banana	banana	helicopter	frog	pig	present	
cucumber	cucumber	jumper	mouse	squirrel	present	
pook	book	jeans	chips	rocket	absent	Similar
koon	moon	towel	plate	bin	absent	Different
bird	bird	goat	camera	tomato	present	
pib	bib	toast	window	pen	absent	Onset
poat	boat	hammer	flower	cheese	absent	Similar
pizza	pizza	duck	monkey	t-shirt	present	
silk	milk	box	clock	pushchair	absent	Different
pus	bus	hat	table	pear	absent	Onset
penguin	penguin	rabbit	lollipop	bag	present	
pall	ball	house	spoon	trousers	absent	Similar
keg	leg	sink	biscuit	train	absent	Different
cherry	cherry	cow	knife	panda	present	
poot	boot	chair	dummy	peas	absent	Onset
ped	bed	truck	grapes	sandwich	absent	Similar
elephant	elephant	lamp	butterfly	raspberry	present	
kose	nose	star	bread	tractor	absent	Different
toor	door	shoes	bucket	tongue	absent	Onset
peanut	peanut	jacket	turtle	horse	present	
zock	sock	glass	mouth	digger	absent	Similar
nake	cake	brush	TV	potty	absent	Different
bear	bear	toothbrush	ambulance	camel	present	
ben	pen	juice	nappy	bus	absent	Onset
gup	cup	swing	raisins	foot	absent	Similar
chocolate	chocolate	ladybird	lion	scissors	present	
moat	coat	doll	bike	pasta	absent	Different
dooth	tooth	watch	balloon	door	absent	Onset
bee	bee	crane	giraffe	ear	present	
gar	car	wall	slide	orange	absent	Similar
mot	cot	sun	icecream	bath	absent	Different
strawberry	strawberry	sheep	gloves	zebra	present	
dree	tree	carrot	bottle	dress	absent	Onset
dongue	tongue	key	spade	button	absent	Similar
dog	dog	teddybear	chicken	cap	present	
mand	hand	fridge	bowl	cushion	absent	Different
blane	plane	apple	fork	blocks	absent	Onset

Table D.1: Experiment 6 - Trial List 1

Target	Rhyme	Unrelated 1	Unrelated 2	Unrelated 3/ Onset	Type	Condition
chocolate	chocolate	ladybird	lion	scissors	present	
elephant	elephant	lamp	butterfly	raspberry	present	
dog	dog	teddy bear	chicken	cap	present	
dooth	tooth	watch	balloon	door	absent	Onset
silk	milk	box	clock	pushchair	absent	Different
peanut	peanut	jacket	turtle	horse	present	
ped	bed	truck	grapes	sandwich	absent	Similar
toor	door	shoes	bucket	tongue	absent	Onset
cat	cat	fish	lemon	radio	present	
keg	leg	sink	biscuit	train	absent	Different
gup	cup	swing	raisins	foot	absent	Similar
pizza	pizza	duck	monkey	t-shirt	present	
blane	plane	apple	fork	blocks	absent	Onset
koon	moon	towel	plate	bin	absent	Different
bee	bee	crane	giraffe	ear	present	
zock	sock	glass	mouth	digger	absent	Similar
ben	pen	juice	nappy	bus	absent	Onset
cucumber	cucumber	jumper	mouse	squirrel	present	
mot	cot	sun	ice cream	bath	absent	Different
poat	boat	hammer	flower	cheese	absent	Similar
bear	bear	toothbrush	ambulance	camel	present	
poot	boot	chair	dummy	peas	absent	Onset
moat	coat	doll	bike	pasta	absent	Different
banana	banana	helicopter	frog	pig	present	
pook	book	jeans	chips	rocket	absent	Similar
dree	tree	carrot	bottle	dress	absent	Onset
penguin	penguin	rabbit	lollipop	bag	present	
kose	nose	star	bread	tractor	absent	Different
pall	ball	house	spoon	trousers	absent	Similar
cherry	cherry	cow	knife	panda	present	
pus	bus	hat	table	pear	absent	Onset
mand	hand	fridge	bowl	cushion	absent	Different
bird	bird	goat	camera	tomato	present	
dongue	tongue	key	spade	button	absent	Similar
pib	bib	toast	window	pen	absent	Onset
strawberry	strawberry	sheep	gloves	zebra	present	
nake	cake	brush	TV	potty	absent	Different
gar	car	wall	slide	orange	absent	Similar
mand	hand	fridge	bowl	cushion	absent	Different
blane	plane	apple	fork	blocks	absent	Onset

Table D.2: Experiment 6 - Trial List 2

Target	Rhyme	Unrelated 1	Unrelated 2	Unrelated 3/ Onset	Type	Condition
penguin	penguin	rabbit	lollipop	bag	present	
peanut	peanut	jacket	turtle	horse	present	
chocolate	chocolate	ladybird	lion	scissors	present	
kose	nose	star	bread	tractor	absent	Different
ben	pen	juice	nappy	bus	absent	Onset
dog	dog	teddy bear	chicken	cap	present	
pook	book	jeans	chips	rocket	absent	Similar
moat	coat	doll	bike	pasta	absent	Different
strawberry	strawberry	sheep	gloves	zebra	present	
poot	boot	chair	dummy	peas	absent	Onset
dongue	tongue	key	spade	button	absent	Similar
bird	bird	goat	camera	tomato	present	
koon	moon	towel	plate	bin	absent	Different
pus	bus	hat	table	pear	absent	Onset
cucumber	cucumber	jumper	mouse	squirrel	present	
gar	car	wall	slide	orange	absent	Similar
mand	hand	fridge	bowl	cushion	absent	Different
elephant	elephant	lamp	butterfly	raspberry	present	
pib	bib	toast	window	pen	absent	Onset
zock	sock	glass	mouth	digger	absent	Similar
pizza	pizza	duck	monkey	t-shirt	present	
keg	leg	sink	biscuit	train	absent	Different
blane	plane	apple	fork	blocks	absent	Onset
bear	bear	toothbrush	ambulance	camel	present	
gup	cup	swing	raisins	foot	absent	Similar
silk	milk	box	clock	pushchair	absent	Different
banana	banana	helicopter	frog	pig	present	
dooth	tooth	watch	balloon	door	absent	Onset
pall	ball	house	spoon	trousers	absent	Similar
cat	cat	fish	lemon	radio	present	
nake	cake	brush	TV	potty	absent	Different
dree	tree	carrot	bottle	dress	absent	Onset
cherry	cherry	cow	knife	panda	present	
ped	bed	truck	grapes	sandwich	absent	Similar
mot	cot	sun	ice cream	bath	absent	Different
bee	bee	crane	giraffe	ear	present	
toor	door	shoes	bucket	tongue	absent	Onset
poat	boat	hammer	flower	cheese	absent	Similar
mand	hand	fridge	bowl	cushion	absent	Different
blane	plane	apple	fork	blocks	absent	Onset

Table D.3: Experiment 6 - Trial List 3

Target	Rhyme	Unrelated 1	Unrelated 2	Unrelated 3/ Onset	Type	Condition
cherry	cherry	cow	knife	panda	present	
penguin	penguin	rabbit	lollipop	bag	present	
bear	bear	toothbrush	ambulance	camel	present	
gar	car	wall	slide	orange	absent	Similar
pib	bib	toast	window	pen	absent	Onset
strawberry	strawberry	sheep	gloves	zebra	present	
nake	cake	brush	TV	potty	absent	Different
pook	book	jeans	chips	rocket	absent	Similar
elephant	elephant	lamp	butterfly	raspberry	present	
dooth	tooth	watch	balloon	door	absent	Onset
mand	hand	fridge	bowl	cushion	absent	Different
pizza	pizza	duck	monkey	t-shirt	present	
gup	cup	swing	raisins	foot	absent	Similar
poot	boot	chair	dummy	peas	absent	Onset
bee	bee	crane	giraffe	ear	present	
keg	leg	sink	biscuit	train	absent	Different
poat	boat	hammer	flower	cheese	absent	Similar
banana	banana	helicopter	frog	pig	present	
dree	tree	carrot	bottle	dress	absent	Onset
kose	nose	star	bread	tractor	absent	Different
dog	dog	teddybear	chicken	cap	present	
pall	ball	house	spoon	trousers	absent	Similar
pus	bus	hat	table	pear	absent	Onset
chocolate	chocolate	ladybird	lion	scissors	present	
mot	cot	sun	ice cream	bath	absent	Different
ped	bed	truck	grapes	sandwich	absent	Similar
bird	bird	goat	camera	tomato	present	
blane	plane	apple	fork	blocks	absent	Onset
moat	coat	doll	bike	pasta	absent	Different
cucumber	cucumber	jumper	mouse	squirrel	present	
zock	sock	glass	mouth	digger	absent	Similar
toor	door	shoes	bucket	tongue	absent	Onset
cat	cat	fish	lemon	radio	present	
silk	milk	box	clock	pushchair	absent	Different
dongue	tongue	key	spade	button	absent	Similar
peanut	peanut	jacket	turtle	horse	present	
ben	pen	juice	nappy	bus	absent	Onset
koon	moon	towel	plate	bin	absent	Different
mand	hand	fridge	bowl	cushion	absent	Different
blane	plane	apple	fork	blocks	absent	Onset

Table D.4: Experiment 6 - Trial List 4

Appendix E

Experiment 7

Target	Rhyme	Distractor	First Phoneme	Vowel	Direction
pin	bin	bus	Voice Mismatch	Mismatch	-
peach	beach	bag	Voice Mismatch	Mismatch	-
pear	bear	bib	Voice Mismatch	Mismatch	-
park	bark	boat	Voice Mismatch	Mismatch	-
pill	bill	boot	Voice Mismatch	Mismatch	-
pole	bowl	bat	Voice Mismatch	Mismatch	-
coal	goal	game	Voice Mismatch	Mismatch	-
coat	goat	game	Voice Mismatch	Mismatch	-
fan	van	veil	Voice Mismatch	Mismatch	-
bin	pin	pope	Voice Mismatch	Mismatch	-
beach	peach	pig	Voice Mismatch	Mismatch	-
bear	pear	pipe	Voice Mismatch	Mismatch	-
bark	park	pen	Voice Mismatch	Mismatch	-
bill	pill	pan	Voice Mismatch	Mismatch	-
bowl	pole	pit	Voice Mismatch	Mismatch	-
goal	coal	cab	Voice Mismatch	Mismatch	-
goat	coat	coin	Voice Mismatch	Mismatch	-
van	fan	fish	Voice Mismatch	Mismatch	-
pin	bin	bill	Voice Mismatch	Complete Match	-
peach	beach	bead	Voice Mismatch	Complete Match	-
peas	bees	beet	Voice Mismatch	Complete Match	-
pole	bowl	boat	Voice Mismatch	Complete Match	-
coal	goal	goat	Voice Mismatch	Complete Match	-
bin	pin	pig	Voice Mismatch	Complete Match	-
beach	peach	peel	Voice Mismatch	Complete Match	-
bees	peas	peel	Voice Mismatch	Complete Match	-
bowl	pole	pope	Voice Mismatch	Complete Match	-
goal	coal	cone	Voice Mismatch	Complete Match	-
peach	beach	bill	Voice Mismatch	No Mismatch	-
pear	bear	beer	Voice Mismatch	No Mismatch	-
pier	beer	bear	Voice Mismatch	No Mismatch	-
pill	bill	bees	Voice Mismatch	No Mismatch	-
peas	bees	bill	Voice Mismatch	No Mismatch	-
pole	bowl	boot	Voice Mismatch	No Mismatch	-
tear	deer	date	Voice Mismatch	No Mismatch	-
coat	goat	goose	Voice Mismatch	No Mismatch	-
bin	pin	peel	Voice Mismatch	No Mismatch	-
bear	pear	pier	Voice Mismatch	No Mismatch	-
beer	pier	pear	Voice Mismatch	No Mismatch	-
bill	pill	peas	Voice Mismatch	No Mismatch	-
bees	peas	pill	Voice Mismatch	No Mismatch	-
bowl	pole	pool	Voice Mismatch	No Mismatch	-
deer	tear	tin	Voice Mismatch	No Mismatch	-
goat	coat	cot	Voice Mismatch	No Mismatch	-

Table E.1: Experiment 7 - Experimental Trials (Voice Mismatch Condition)

Target	Rhyme	Distractor	First Phoneme	Vowel	Direction
tear	pier	pot	Coronal/Non-Coronal	Mismatch	Forward
till	pill	pipe	Coronal/Non-Coronal	Mismatch	Forward
tin	pin	palm	Coronal/Non-Coronal	Mismatch	Forward
tool	pool	pine	Coronal/Non-Coronal	Mismatch	Forward
torch	porch	pearl	Coronal/Non-Coronal	Mismatch	Forward
deer	beer	bath	Coronal/Non-Coronal	Mismatch	Forward
tea	key	cow	Coronal/Non-Coronal	Mismatch	Forward
table	cable	corn	Coronal/Non-Coronal	Mismatch	Forward
date	gate	goal	Coronal/Non-Coronal	Mismatch	Forward
pier	tear	tile	Coronal/Non-Coronal	Mismatch	Reverse
pill	till	tank	Coronal/Non-Coronal	Mismatch	Reverse
pin	tin	tail	Coronal/Non-Coronal	Mismatch	Reverse
pool	tool	tongue	Coronal/Non-Coronal	Mismatch	Reverse
porch	torch	tooth	Coronal/Non-Coronal	Mismatch	Reverse
beer	deer	door	Coronal/Non-Coronal	Mismatch	Reverse
key	tea	toe	Coronal/Non-Coronal	Mismatch	Reverse
cable	table	tower	Coronal/Non-Coronal	Mismatch	Reverse
gate	date	duck	Coronal/Non-Coronal	Mismatch	Reverse
till	pill	pit	Coronal/Non-Coronal	Complete Match	Forward
tin	pin	pill	Coronal/Non-Coronal	Complete Match	Forward
deer	beer	beard	Coronal/Non-Coronal	Complete Match	Forward
table	cable	cage	Coronal/Non-Coronal	Complete Match	Forward
date	gate	game	Coronal/Non-Coronal	Complete Match	Forward
pill	till	tin	Coronal/Non-Coronal	Complete Match	Reverse
pin	tin	till	Coronal/Non-Coronal	Complete Match	Reverse
pool	tool	tooth	Coronal/Non-Coronal	Complete Match	Reverse
key	tea	teeth	Coronal/Non-Coronal	Complete Match	Reverse
cable	table	tape	Coronal/Non-Coronal	Complete Match	Reverse
tear	pier	pear	Coronal/Non-Coronal	No Mismatch	Forward
till	pill	pen	Coronal/Non-Coronal	No Mismatch	Forward
tin	pin	pen	Coronal/Non-Coronal	No Mismatch	Forward
tool	pool	pope	Coronal/Non-Coronal	No Mismatch	Forward
torch	porch	pot	Coronal/Non-Coronal	No Mismatch	Forward
deer	beer	bill	Coronal/Non-Coronal	No Mismatch	Forward
tea	key	king	Coronal/Non-Coronal	No Mismatch	Forward
table	cable	cap	Coronal/Non-Coronal	No Mismatch	Forward
pier	tear	till	Coronal/Non-Coronal	No Mismatch	Reverse
pill	till	tent	Coronal/Non-Coronal	No Mismatch	Reverse
pin	tin	tent	Coronal/Non-Coronal	No Mismatch	Reverse
pool	tool	toast	Coronal/Non-Coronal	No Mismatch	Reverse
porch	torch	top	Coronal/Non-Coronal	No Mismatch	Reverse
beer	deer	date	Coronal/Non-Coronal	No Mismatch	Reverse
key	tea	tin	Coronal/Non-Coronal	No Mismatch	Reverse
cable	table	tap	Coronal/Non-Coronal	No Mismatch	Reverse

Table E.2: Experiment 7 - Experimental Trials (Coronal/Non-Coronal Condition). Direction further subdivides this condition.

Target	Rhyme	Distractor	First Phoneme	Vowel	Direction
cap	map	mole	Complete Mismatch	Mismatch	-
meat	seat	soap	Complete Mismatch	Mismatch	-
bell	shell	ship	Complete Mismatch	Mismatch	-
house	mouse	milk	Complete Mismatch	Mismatch	-
can	man	moose	Complete Mismatch	Mismatch	-
cot	knot	knife	Complete Mismatch	Mismatch	-
hook	book	bush	Complete Mismatch	Mismatch	-
bark	shark	shell	Complete Mismatch	Mismatch	-
shed	bed	bird	Complete Mismatch	Mismatch	-
map	cap	coil	Complete Mismatch	Mismatch	-
seat	meat	moon	Complete Mismatch	Mismatch	-
shell	bell	box	Complete Mismatch	Mismatch	-
mouse	house	hand	Complete Mismatch	Mismatch	-
man	can	couch	Complete Mismatch	Mismatch	-
knot	cot	cake	Complete Mismatch	Mismatch	-
book	hook	hair	Complete Mismatch	Mismatch	-
shark	bark	bell	Complete Mismatch	Mismatch	-
bed	shed	shark	Complete Mismatch	Mismatch	-
cap	map	mat	Complete Mismatch	Complete Match	-
meat	seat	seed	Complete Mismatch	Complete Match	-
bell	shell	shed	Complete Mismatch	Complete Match	-
hook	book	bush	Complete Mismatch	Complete Match	-
shed	bed	bell	Complete Mismatch	Complete Match	-
map	cap	cat	Complete Mismatch	Complete Match	-
seat	meat	meal	Complete Mismatch	Complete Match	-
shell	bell	bed	Complete Mismatch	Complete Match	-
book	hook	hood	Complete Mismatch	Complete Match	-
bed	shed	shell	Complete Mismatch	Complete Match	-
cap	map	maze	Complete Mismatch	No Mismatch	-
meat	seat	sieve	Complete Mismatch	No Mismatch	-
bell	shell	ship	Complete Mismatch	No Mismatch	-
house	mouse	map	Complete Mismatch	No Mismatch	-
can	man	mouse	Complete Mismatch	No Mismatch	-
hook	book	bowl	Complete Mismatch	No Mismatch	-
bark	shark	shawl	Complete Mismatch	No Mismatch	-
shed	bed	bin	Complete Mismatch	No Mismatch	-
cap	map	maze	Complete Mismatch	No Mismatch	-
meat	seat	sieve	Complete Mismatch	No Mismatch	-
bell	shell	ship	Complete Mismatch	No Mismatch	-
house	mouse	map	Complete Mismatch	No Mismatch	-
can	man	mouse	Complete Mismatch	No Mismatch	-
hook	book	bowl	Complete Mismatch	No Mismatch	-
bark	shark	shawl	Complete Mismatch	No Mismatch	-
shed	bed	bin	Complete Mismatch	No Mismatch	-

Table E.3: Experiment 7 - Experimental Trials (Complete Mismatch Condition)

Appendix F

Experiment 8

Target	Onset	Distractor	First Phoneme	Direction
bush	bin	pin	Voice Mismatch	-
bab	beach	peach	Voice Mismatch	-
bim	bear	pear	Voice Mismatch	-
boaf	bark	park	Voice Mismatch	-
boof	bill	pill	Voice Mismatch	-
bav	bowl	pole	Voice Mismatch	-
gake	goal	coal	Voice Mismatch	-
gak	goat	coat	Voice Mismatch	-
veis	van	fan	Voice Mismatch	-
poat	pin	bin	Voice Mismatch	-
pif	peach	beach	Voice Mismatch	-
pise	pear	bear	Voice Mismatch	-
pesh	park	bark	Voice Mismatch	-
pag	pill	bill	Voice Mismatch	-
pim	pole	bowl	Voice Mismatch	-
cak	coal	goal	Voice Mismatch	-
coise	coat	goat	Voice Mismatch	-
fim	fan	van	Voice Mismatch	-
bish	bin	pin	Voice Mismatch	-
beel	beach	peach	Voice Mismatch	-
beeg	bees	peas	Voice Mismatch	-
boaf	bowl	pole	Voice Mismatch	-
goam	goal	coal	Voice Mismatch	-
pif	pin	bin	Voice Mismatch	-
peab	peach	beach	Voice Mismatch	-
peab	peas	bees	Voice Mismatch	-
poat	pole	bowl	Voice Mismatch	-
cobe	coal	goal	Voice Mismatch	-
bish	beach	peach	Voice Mismatch	-
baim	bear	pear	Voice Mismatch	-
bearg	beer	pier	Voice Mismatch	-
beesh	bill	pill	Voice Mismatch	-
bish	bees	peas	Voice Mismatch	-
boof	bowl	pole	Voice Mismatch	-
diff	deer	tear	Voice Mismatch	-
gog	goat	coat	Voice Mismatch	-
peem	pin	bin	Voice Mismatch	-
pame	pear	bear	Voice Mismatch	-
peard	pier	beer	Voice Mismatch	-
peash	pill	bill	Voice Mismatch	-
pish	peas	bees	Voice Mismatch	-
poot	pole	bowl	Voice Mismatch	-
tiss	tear	deer	Voice Mismatch	-
com	coat	goat	Voice Mismatch	-

Table F.1: Experiment 8 - Experimental Trials (Voice Mismatch Condition)

Target	Onset	Distractor	First Phoneme	Direction
pon	pier	tear	Coronal/Non-Coronal	Forward
pise	pill	till	Coronal/Non-Coronal	Forward
pash	pin	tin	Coronal/Non-Coronal	Forward
pime	pool	tool	Coronal/Non-Coronal	Forward
peart	porch	torch	Coronal/Non-Coronal	Forward
barl	beer	deer	Coronal/Non-Coronal	Forward
cowf	key	tea	Coronal/Non-Coronal	Forward
corb	cable	table	Coronal/Non-Coronal	Forward
goab	gate	date	Coronal/Non-Coronal	Forward
tife	tear	pier	Coronal/Non-Coronal	Reverse
tam	till	pill	Coronal/Non-Coronal	Reverse
tade	tin	pin	Coronal/Non-Coronal	Reverse
tud	tool	pool	Coronal/Non-Coronal	Reverse
toog	torch	porch	Coronal/Non-Coronal	Reverse
dood	deer	beer	Coronal/Non-Coronal	Reverse
toaf	tea	key	Coronal/Non-Coronal	Reverse
touf	table	cable	Coronal/Non-Coronal	Reverse
dup	date	gate	Coronal/Non-Coronal	Reverse
pim	pill	till	Coronal/Non-Coronal	Forward
pish	pin	tin	Coronal/Non-Coronal	Forward
bearf	beer	deer	Coronal/Non-Coronal	Forward
cashe	cable	table	Coronal/Non-Coronal	Forward
gake	gate	date	Coronal/Non-Coronal	Forward
tib	till	pill	Coronal/Non-Coronal	Reverse
tish	tin	pin	Coronal/Non-Coronal	Reverse
toog	tool	pool	Coronal/Non-Coronal	Reverse
teep	tea	key	Coronal/Non-Coronal	Reverse
tage	table	cable	Coronal/Non-Coronal	Reverse
peart	pier	tear	Coronal/Non-Coronal	Forward
pesh	pill	till	Coronal/Non-Coronal	Forward
peb	pin	tin	Coronal/Non-Coronal	Forward
poat	pool	tool	Coronal/Non-Coronal	Forward
pon	porch	torch	Coronal/Non-Coronal	Forward
bish	beer	deer	Coronal/Non-Coronal	Forward
kib	key	tea	Coronal/Non-Coronal	Forward
cairsh	cable	table	Coronal/Non-Coronal	Forward
tearg	tear	pier	Coronal/Non-Coronal	Reverse
tet	till	pill	Coronal/Non-Coronal	Reverse
tesh	tin	pin	Coronal/Non-Coronal	Reverse
tobe	tool	pool	Coronal/Non-Coronal	Reverse
tob	torch	porch	Coronal/Non-Coronal	Reverse
ditt	deer	beer	Coronal/Non-Coronal	Reverse
tiss	tea	key	Coronal/Non-Coronal	Reverse
tearg	table	cable	Coronal/Non-Coronal	Reverse

Table F.2: Experiment 8 - Experimental Trials (Coronal/Non-Coronal Condition). Direction further subdivides this condition.

Target	Onset	Distractor	First Phoneme	Direction
mogue	map	cap	Complete Mismatch	-
soag	seat	meat	Complete Mismatch	-
shiff	shell	bell	Complete Mismatch	-
mib	mouse	house	Complete Mismatch	-
mook	man	can	Complete Mismatch	-
knime	knot	cot	Complete Mismatch	-
budd	book	hook	Complete Mismatch	-
shen	shark	bark	Complete Mismatch	-
bersh	bed	shed	Complete Mismatch	-
coish	cap	map	Complete Mismatch	-
moob	meat	seat	Complete Mismatch	-
boff	bell	shell	Complete Mismatch	-
hab	house	mouse	Complete Mismatch	-
cout	can	man	Complete Mismatch	-
cabe	cot	knot	Complete Mismatch	-
hairn	hook	book	Complete Mismatch	-
beb	bark	shark	Complete Mismatch	-
sharf	shed	bed	Complete Mismatch	-
maff	map	cap	Complete Mismatch	-
seeb	seat	meat	Complete Mismatch	-
shek	shell	bell	Complete Mismatch	-
budd	book	hook	Complete Mismatch	-
beb	bed	shed	Complete Mismatch	-
cag	cap	map	Complete Mismatch	-
meeg	meat	seat	Complete Mismatch	-
bem	bell	shell	Complete Mismatch	-
hoob	hook	book	Complete Mismatch	-
shen	shed	bed	Complete Mismatch	-
maig	map	cap	Complete Mismatch	-
siff	seat	meat	Complete Mismatch	-
shik	shell	bell	Complete Mismatch	-
mab	mouse	house	Complete Mismatch	-
mout	man	can	Complete Mismatch	-
boam	book	hook	Complete Mismatch	-
shawb	shark	bark	Complete Mismatch	-
bim	bed	shed	Complete Mismatch	-
kashe	cap	map	Complete Mismatch	-
mig	meat	seat	Complete Mismatch	-
bim	bell	shell	Complete Mismatch	-
han	house	mouse	Complete Mismatch	-
coub	can	man	Complete Mismatch	-
hode	hook	book	Complete Mismatch	-
bawb	bark	shark	Complete Mismatch	-
shik	shed	bed	Complete Mismatch	-

Table F.3: Experiment 8 - Experimental Trials (Complete Mismatch Condition)