Language-mediated Visual Attention in Toddlers

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Abstract

Language plays an important role in driving visual attention. The aim of this thesis is to gain a better understanding of how language may mediate visual attention in toddlers, who begin to learn about the world through language communication. In Part I of the thesis, I examine the time course and order in which different types of stored linguistic representations are activated during spoken-word recognition. In Experiments 1–4, I demonstrate that the four-picture adult visual world paradigm (VWP) in combination with growth curve analysis and mixed effects modelling (Mirman, 2014), is a suitable tool for measuring language-mediated cognitive processes in toddlers. The results indicate that, like adults, toddlers extract phonological information faster than semantic information during spoken-word recognition, and that these differences hold irrespective of whether the semantic information is taxonomic or thematic in character. Moreover, phonological effects are re-

lated to the toddler's overall vocabulary size, suggesting a role for emerging phonological organisation and/or word familiarity in the phonological decoding of words. The results of the study are compatible with an interactive view of language-mediated visual attention in toddlers whereby implicitly generated phonological codes and speech-driven phonological encoding work together to support referent identification.

In Part II of the thesis, I investigate how language as an attentional set may guide toddlers' visual attention. Specifically, I examine the role of distractor inhibition during language-mediated visual attention using a negative priming (NP) procedure. NP refers to the impaired response observed when a participant has to respond to a stimulus identity or location that they previously ignored (i.e., identity or location NP). Any observed NP effect would suggest that language-mediated selective attention involves inhibition of response towards the distractor. In Experiment 5 (six conditions), participants were shown trials each containing a prime phase, followed by a probe phase. In both phases, participants heard the target picture being named and were allowed to look freely at the pictures. In all conditions, participants were 'on-task' and showed greater than chance target preference after target label onset. No location NP effect was observed when the prime stimuli were repeated in the same locations in the probe phase, or when the probe stimuli were novel. However, location NP was observed when the prime stimuli were repeated in swapped locations in the probe phase. That is, there was significantly less target preference in the ignored location–attended identity condition. Rather than by distractor inhibition, these results could be better explained by the mismatching of feature–location–response bindings in the prime and probe phases. These findings indicate that language drives the encoding of temporary episodic representations of events, which are stored, retrieved and compared with later events, and may mediate visual attention.

In sum, this thesis demonstrates that language-mediated visual attention involves the activation and retrieval of 'higher level' representations, which are then matched and integrated with the 'lower level' visual and auditory inputs. While Part I demonstrates how relatively long-term lexical-semantic knowledge mediates visual attention, Part II demonstrates how recently encountered events are encoded into episodic representations, retrieved and in turn, influence mediated visual attention.

Publication arising from this thesis

Experiments 1–3 Chow, J., Aimola Davies, A., & Plunkett, K. (under review). Spoken-word recognition in 2-year-olds: The tug of war between phonological and semantic activation. Journal of Memory and Language.

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Chapter 1

General Introduction

1.1 Language-mediated Visual Attention

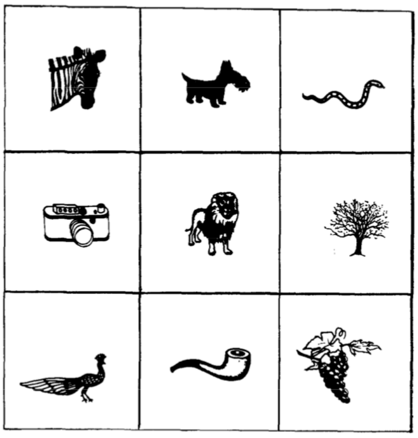

Figure 1.1. In Cooper (1974), participants were presented with a grid of nine pictures, and heard a story. When participants heard the word ‘lion’, their eyes were drawn to the picture of the lion. Moreover, upon hearing the word ‘Africa’, they were more likely to fixate the pictures of lion, zebra and snake.

Language plays an important role in driving visual attention. Cooper (1974) first demonstrated experimentally that adults would spontaneously and automatically fixate an object that was either named or relevant to what was just said. As seen in Figure 1.2, participants were presented with a grid of nine pictures and heard a story. When participants heard the word 'lion', their eyes were drawn to the picture of the lion. Moreover, upon hearing the word 'Africa', they were more likely to fixate the pictures of lion, zebra, and snake. These findings provided concrete evidence that language mediates where the listener will look, and that language-mediated eye-movements reflect the mental activity of language processing.

Over the past 20 years, Cooper's (1974) paradigm, later termed the *Visual World Paradigm* (VWP), has become a popular tool for the study of language-mediated visual attention in adults (see Huettig, Rommers, & Meyer, 2011, for a detailed review). There have been two approaches to studying language-mediated visual attention. In psycholinguistic research (the 'psycholinguistic' approach), language-mediated visual attention as a measurement is used to infer the organisation of the mental lexicon and the order in which different types of linguistic representations are activated and matched during spoken-word recognition. Take Cooper's (1974) study as an example, the fact that participants fixated the related but unnamed pictures suggests that not only the target representation but also the target-related representations were activated and retrieved from the lexical-semantic system. The retrieved lexical-semantic representations are then matched with the current visual input, which in turn leads to increased visual attention. The mechanism by which linguistic representations mediate oculomotor movements, however, has been of little concern.

In contrast, visual search studies (the 'visual search' approach) are interested in how an attentional set (e.g., search for animals) may drive visual selective attention. Traditionally, researchers focused on examining factors that may influence visual search efficiency, as measured by reaction times (RT) or error rates. For example, it has been shown that RT for visual search increases with set size, i.e., the total number of stimuli on the screen (Palmer, 1995). Moreover, visual search could be performed in a serial or parallel manner depending on the degree of visual similarity of the target and distractors (Christ, 1975; Nagy & Sanchez, 1990; Treisman & Gelade, 1980). In most of these visual search studies, the attentional set is assigned through language, either by written or verbal instructions. However, Huettig, Olivers, & Hartsuiker (2011) pointed out that the visual search literature has largely avoided discussing the actual mechanism of attentional-set driven visual attention, i.e., the mechanism by which top-down semantics (of the attentional set) and bottom-up visual inputs interact to drive oculomotor movements. Huettig, Olivers, & Hartsuiker (2011) suggest that the VWP is, in fact, the ideal tool to investigate the top-down and bottom-up interaction during visual search. Recently, De Groot et al. (2015) have used the VWP to directly investigate the relative importance of semantic and visual information in driving language-mediated visual search.

In sum, language-mediated visual attention reflect at least two types of mental processes. The 'psycholinguistic' approach emphasises on studying what types of lexical-semantic representations are activated and retrieved during spoken-word and picture recognition. The 'visual search' approach emphasises on understanding how visual attention is driven by the interaction between top-down representations and bottom-up inputs.

The aim of this thesis is to gain a better understanding of the mechanism of language-mediated visual attention by studying 2-year-old toddlers, who are at an early stage of language acquisition. Infants begin to show signs of spoken-word recognition at around 9-months (Benedict, 1979) and are estimated to understand hundreds of words by 24-months (Hamilton et al., 2000). With an increased level of command of speech comprehension and production at around 24-months, toddlers begin to learn about the world through language communication. Using the 'psycholinguistic' approach of the VWP, this thesis examines the mental processes involved in spoken-word recognition in 24- to 30-month-old toddlers. Using the 'visual search' approach, this thesis examines how language acts as an attentional set to guide toddlers' visual attention, and what types of mental processes are involved to mediate language and visual attention.

The rest of this chapter will provide an overview of the existing psycholinguistic literature on language-mediated visual attention in adults and infants[1]. I will first provide definitions of important terms on the subjects of spoken-word recognition and the mental lexicon, and then review existing findings on the time course and order of the activation of lexical-semantic representations during spoken-word recognition in adults using the four-picture visual world paradigm (VWP), and in infants using the two-picture inter-

[1]An overview of the language-mediated visual search approach will be provided in Part II Chapter 7.

modal preferential looking (IPL) paradigm.

1.2 The Mental Lexicon

One of the most important aspects of language development research is to understand the process and mechanism of spoken-word recognition. How do infants and toddlers store linguistic knowledge? How do they decipher and recognise speech sounds, and match them with their existing linguistic knowledge? How may individual differences of vocabulary development predict individual differences in spoken-word recognition, and generally cognitive processing of the visual world?

1.2.1 What types of information are stored with the word entry?

Phonology (sound) and semantics (meaning) are the two main types of linguistic representations. Phonological representations refer to the mental representations of sound patterns of language(s), for example, the knowledge that the phonemes /d/, /o/ and /g/ form the word 'dog'. Phonological relations have been studied using mainly the lexical decision task in children and adults. In a typical lexical decision task, participants are presented with a sequence of letter strings: their task is to decide whether each letter string represents a word or not, by pressing a button. Adult lexical decision priming studies have demonstrated that, participants' lexical decision response is facilitated if the prime and target words share the same onset consonant (e.g., ‘dog’ and ‘doll’) (Marslen-Wilson & Zwitserlood, 1989; Slowiaczek et al., 1987; Zwitserlood, 1989). This effect is termed *cohort priming*. Similarly, it has been demonstrated that lexical decision is facilitated by a rhyme prime e.g., ‘dog’ and ‘fog’, (Marslen-Wilson et al., 1996; Slowiaczek et al., 1987), an embedded prime, e.g., ‘bone’ and ‘trombone’ (Shillcock, 1990), a morphologically-similar prime, e.g., ‘submit’ and ‘permit’, or by words that share the same segment, e.g., ‘tango’ and ‘cargo’ (Emmorey, 1989). These phonological priming effects indicate that the adult mental lexicon encodes phonological relations between words, and that phonologically-similar words can be ‘pre-activated’ by the prime word.

Semantic representations refer to the mental representations of the characteristics and relations within and between objects, people, and events. Taxonomic and thematic relations are the two most studied types of semantic relation. Taxonomic relations refer to the classification or hierarchy of items. Items that are taxonomically-related tend to resemble each other, sharing perceptual, biological or functional properties (e.g., Medin & Smith, 1984; Smith & Medin, 1981). Taxonomic categories can be formed at different levels in the hierarchy, such as basic, subordinate and superordinate level categories. For example, labrador and collie belong to the category of dog; dog and horse belong to the category of mammals; mammals and birds belong to the category of animal.

In contrast, thematic relations refer to the grouping of items co-occurring in the same space and time, often based on memory and personal experience.

Rather than resembling each other, thematically-related items tend to complement each other. Amongst the most studied types of thematic relations are functional relations. These include at least two sub-types: instrument and script (Moss et al., 1995). The instrument relation describes word pairs in which one performs some action on the other. For example, shampoo is used on hair. The script relation describes the relationship between a context and items that occur or appear in the same time and space. For example, one finds sheep in a farm. Other commonly studied thematic relations include part-whole (e.g., coin is made of copper), causal-relation (e.g., wind propels a sail) and temporal-relation (e.g., breakfast takes place before lunch). Often, thematically-related items are related in more than one way (Lin & Murphy, 2001). For example, chalk and blackboard are both instrument- and script-related, because chalk is used to write on the blackboard, and chalk is often found resting on the ledge of a blackboard.

It is well established that participants' decision in a lexical decision task is faster or more accurate when they see two taxonomically-related, thematically-related and/or associated words[2] in succession. For example, the reaction time to deciding whether 'nurse' is a word is faster if the previous word is doctor, compared with dog (Antos, 1979; D. E. Meyer & Schvaneveldt,

[2]Word association norms are collected by presenting the participants with a word, and asking them to name any words that come to mind. Commonly cited word association norms include the Birkbeck Word Association Norms (Moss & Older, 1996), Edinburgh Associative Thesaurus (Kiss et al., 1972) and the University of South Florida Free Association Norms (D. L. Nelson et al., 2004). Words that are associated are not necessarily semantically-related. For example, iceberg is associated with lettuce, but they are neither taxonomically nor thematically related. Similarly, taxonomically- and thematically-related words are not necessarily associated. For example, the taxonomic pair dog and cat are associated, while dog and horse are not associated; the thematic pair cheese and mouse are associated, while cheese and fridge are not associated.

1971). Moreover, Rosch (1975) found that seeing a category name before a same/different decision task could facilitate participants' responses. In sum, findings of semantic lexical decision tasks indicate that the adult mental lexicon encodes both taxonomic and thematic relations, and that hearing one word could 'pre-activate' semantically-related words.

1.2.2 Models of Spoken-Word Recognition

The aim of modelling lexical access is to understand how linguistic representations are stored and retrieved from the lexicon during spoken-word recognition. The metaphor of activation is used in most models of lexical access. One of the earliest models of lexical access (Morton, 1969) assumes that each word in the lexicon is separately represented by a device called a logogen, where phonological, semantic and syntactic representations are stored. During word recognition, sensory inputs are compared with the stored phonological representations simultaneously in all logogens. Logogens that match with the sensory input, as well as the context, receive a higher activation. Word recognition takes place when a logogen reaches its activation threshold and fires. At this point, all stored representations become available for further processing. Logogens that are frequently selected have a lowered activation threshold than words that are less frequently selected. The metaphor of activation remains popular in other models.

The interactive activation model (McClelland & Rumelhart, 1981) contends that word recognition involves both bottom-up and top-down processing at three interactive levels: feature, phoneme (or letter), and word form. Individual units at each level are called nodes. There are both excitatory and inhibitory connections between nodes within levels and between adjacent levels. For example, in bottom-up processing, incoming acoustic features of the spoken-word 'dog' activates the relevant phonemes /d/, /o/ and /g/ and inhibits the irrelevant phonemes. The activated phonemes in turn activates the word form of dog, and inhibit irrelevant word forms. In top-down processing, the word form 'dog' activates the relevant phonemes and inhibits irrelevant phonemes. As a result, the word and phonemes that best match the sensory input would receive the most amount of activation.

The cohort model (Marslen-Wilson, 1987) proposes that the initial sounds of a word activate a set of candidate words in the lexicon that start with the same phonemes. As the word unfolds, candidate words that no longer match the speech input are eliminated until only one word is left. The model assumes that lexical access is a strictly bottom-up manner; top-down effects, such as context, can only influence word selection among the candidate words. For example, upon hearing the first sound /d/ of the word 'dog', candidate words, such as dog, digger and dress, are activated. The TRACE model (McClelland & Elman, 1986) embodies the proposal that word recognition is not only incremental but also continuous, and therefore, words that match the sensory input in the middle or at the end of the signal, such as rhyme words, will also be activated (e.g., dog will activate log). As speech is incremental, most models of lexical access assume that the processing of phonological representations is followed by the processing of semantic representations. Collins & Loftus (1975) assume that each semantic entry (e.g., dog, cat, fur, tail, etc) is separately represented by a node in a semantic network. Nodes of concepts that have a similar meaning (e.g., dog and cat) are connected within the network. When spoken-word or object recognition takes place, activation of the referent node spreads to related nodes (i.e., semantically-related concepts), underpinning the semantic priming effects observed in lexical decision tasks (D. E. Meyer & Schvaneveldt, 1971).

The above-mentioned models are broadly termed localist models, because they all assume that each entry in the lexicon is represented by a node. In contrast, distributed models assume that each entry is represented by a number of different nodes, and that each node takes part in representing many different entries. In the case of lexical access, a distributed model assumes that phonological and semantic features are represented at the same level and can be activated simultaneously (Gaskell & Marslen-Wilson, 1997, 2002). For example, hearing a target word would lead to the activation of phonological and semantic features in parallel. However, as speech is processed incrementally, the activated phonological features tend to be more informative early in the time course. In contrast, semantic features would receive relatively weaker activation and ambiguous activation early in the time course, but become more informative later in the time course as the target word fully unfolds.

1.3 Adult Visual World Paradigm

The visual world paradigm (VWP) has been used to study the order in which phonological representations are retrieved during spoken-word recognition. Allopenna et al. (1998) presented participants with a four-picture display including a target, cohort distractor (same onset consonant and first vowel as target), rhyme distractor (rhymes with target) and unrelated distractor. Upon hearing the target word, participants not only fixated the target picture, but also fixated the cohort distractor. Later in the time course, participants also fixated the rhyme distractor more than the unrelated distractor. Their findings provide strong evidence that spoken-word recognition involves continuous incremental mapping of speech sounds and the automatic activation and elimination of competing phonological representations.

VWP studies have also provided evidence that spoken-word recognition leads to the automatic activation of semantically-related representations. For example, upon hearing a target word (e.g., ‘dog’), the listener is more likely to fixate a taxonomically-related picture (e.g., pig) (Huettig & Altmann, 2005) or a thematically-related picture (e.g., bone) (Mirman & Graziano, 2012; Yee et al., 2009) than an unrelated distractor. These findings are consistent with localist models of semantic memory (e.g., Collins & Loftus, 1975) in which concepts are represented by nodes in a semantic network, and that concepts having a similar meaning share connections with each other within the network. When spoken-word or object recognition takes place, the activation of the referent node spreads to related nodes (i.e., semantically related concepts).

1.3.1 The Tug of War

Huettig & McQueen (2007) used the VWP to investigate the activation of lexical, semantic and visual-shape representations during spoken-word recognition. In Experiment 1, participants heard a sentence containing a target word, e.g., Beaker (Dutch: Beker), and saw a four-picture display containing a phonological distractor, semantic distractor, visual distractor and an unrelated distractor. The phonological distractor, e.g., beaver (Dutch: bever), had the same onset consonant as the target. The semantic distractor, e.g., fork (Dutch: vork), was either taxonomically- or thematically-related to and associated to the target. The visual-shape distractor, e.g., bobbin (Dutch: klos) had the same shape as the target. The unrelated distractor, e.g., umbrella (Dutch: paraplu) was phonologically, semantically and visually dissimilar to the target. The authors found that participants were more likely to fixate the phonological distractor during approximately 300–600ms after the onset of the target word, and the semantic and visual-shape distractors during approximately 400–1000ms after onset. These findings are consistent with the proposal that the activation and matching of phonological, semantic and visual-shape representations are separate processes during spoken-word recognition. Moreover, as speech is processed and recognised incrementally, the matching of phonological representations naturally precedes that of visual-shape and semantic representations.

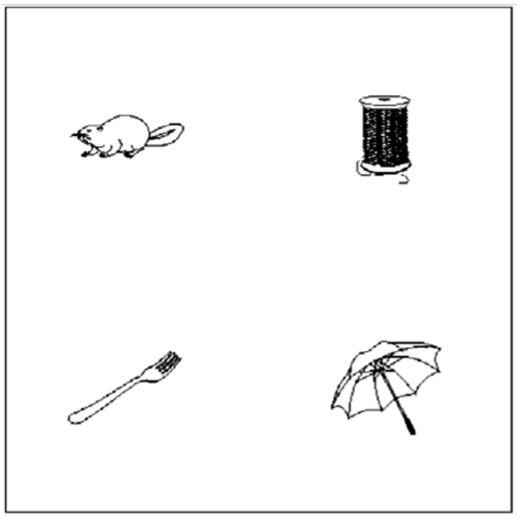

Figure 1.2. In Huettig & McQueen (2007), participants heard a sentence containing a target word, e.g., Beaker, and saw a four-picture display containing a phonological distractor (beaver), semantic distractor (fork), visual distractor (bobbin) and an unrelated distractor (umbrella). The experimental stimuli were in Dutch.

In a second experiment, the design and procedure were identical to the first except that participants were shown the picture display only $200ms$ before target onset. With little time to study the pictures before hearing the target word, participants showed no preference for the phonological distractor. Instead they only preferentially fixated the visual-shape distractor, followed by the semantic distractor. In Experiments 3 and 4, the pictures were replaced by printed words, which appeared either only $200ms$ before target word onset, or from the beginning of the sentence. Interestingly, in both experiments, participants only preferentially fixated the phonological distractor and showed no preference for the visual-shape and semantic distractors. The authors suggested that, compared to phonological representations, semantic and visual-shape representations were irrelevant when processing the printed word.

Altogether, the findings of Huettig & McQueen (2007) highlight several important features of language-mediated visual attention. The matching of auditory and visual stimuli takes place on at least three levels: phonological, semantic and visual-shape, which lead to an attentional preference for phonologically-, semantically- and visually-similar objects. However, the time course of the matching processes depends on the format and presentation duration of the stimuli, and the presence of other relevant objects. One must be cautious when interpreting any lack of preference when using the VWP. For example, the lack of preference for the phonological distractor in Experiment 2 of Huettig & McQueen (2007) does not necessarily suggest the lack of activation of phonologically-related words. It simply suggests the lack of matching between the visual stimuli and the activated representations, possibly due to time and attentional constraints.

1.4 Infant Inter-modal Preferential Looking Paradigm

The study of language-mediated visual attention is not novel in the infant literature; it has been measured using the inter-modal preferential looking (IPL) paradigm since the 1980s. The rationale behind the adult VWP and infant IPL paradigm is the same—both paradigms measure eye-gazes that are interpreted as reflecting language processing. However, there are two main differences between the two paradigms. First, the design of many adult

VWP studies involves target-absent displays, while the design of most infant IPL studies are target-present. In adult VWP studies, the aim is often to investigate visual attention towards non-target but relevant pictures, while the aim of infant IPL studies is often simply to investigate whether infants have learnt and/or understood a target word.

Second, VWP studies tend to use four or more pictures, whilst IPL studies tend to use two pictures. A critical benefit of using more pictures is that it permits simultaneous comparison of several types of experimental stimuli, while a distractor stimulus can still be included as a baseline measure. Automatic eye-tracking facilitates the identification of multiple fixation regions that are horizontally and vertically displaced from each other. Compared to their use with adults, the reliable use of automated eye-trackers with infants is a recent technological development. Typically, laboratories that do not use automated eye-trackers have relied on hand-coding of the eye-movements that are recorded by camera(s) located above or below the screen, permitting accurate identification of horizontally displaced regions of interest but not vertically displaced regions of interest.

In a standard IPL study, infants are shown a pair of pictures, e.g., dog and boat, and hear one of the pictures named in child-directed speech, e.g., "Look at the Dog!". Provided that they know the name of both pictures (as reported by their parents), infants spend more time fixating the named picture compared to the unnamed picture (Golinkoff et al., 1987), thereby indexing their comprehension of the name. IPL studies have shown that infants, like adults, process speech incrementally. For example, Swingley et al. (1999) found that 24-month-olds were delayed at identifying a target when the target and distractor had the same onset consonant, e.g., dog and doll, but not when the target and distractor rhymed with each other, e.g., ball and doll (as it does in American English). Similarly, Fernald et al. (2001) demonstrated that 18- and 21-month-olds could identify the target referent after hearing approximately the first two phonemes of the word. Furthermore, toddlers have shown an adult-like tendency to preferentially fixate a semantically-related, but non-target object. For example, after hearing the word 'strawberry', 36-month-old toddlers would look at the picture of a cookie (which is taxonomically-related to strawberry) more than the picture of a chair (Johnson & Huettig, 2011). This finding indicates that infant word recognition can result not only in the activation of meaning representations for the given word but also related meanings.

Various adaptations of the infant IPL task provide further support for the view that toddlers are sensitive to the phonological and semantic relationship between words. Using a picture prime presented in silence prior to a standard IPL presentation, Mani & Plunkett (2010) found that target recognition was impaired in 18-month-olds when they saw an unrelated prime picture before hearing the target word, but remained intact when they saw a phonologically-related prime. For example, after seeing a prime picture of a bib they looked longer at a picture of a bird (as opposed to a distractor picture of a sheep) upon hearing the word 'bird' than if the prime picture had been of a cake. This result could only have been obtained if infants had implicitly generated the label for the prime picture and that the implicitly generated label influenced processing of the heard label.

Other studies have investigated infant sensitivity to semantic relations between words by presenting pairs of words (a prime and a target) prior to the onset of target and distractor pictures. These studies show that infants respond differentially when a target word is preceded by a semantically related prime compared to an unrelated prime (Arias-Trejo & Plunkett, 2009, 2013; Styles & Plunkett, 2009). For example, Arias-Trejo & Plunkett (2009) found that 21-month-olds (but not 18-month olds) look longer at a target picture of a cat when they heard 'Yesterday, I saw a dog (prime)! Cat (target)!' compared to 'Yesterday, I saw a plate (prime)! Cat (target)!'. These findings reflect the formation of lexical-semantic links in the 21-month-old lexicon. Similar lexical priming studies show that target recognition is impaired when 24-month-olds hear an unrelated prime word, as opposed to a taxonomically- or thematically-related word prime (Arias-Trejo & Plunkett, 2013), indicating that 24-month olds are sensitive to word pairings that are purely taxonomically-related (e.g., 'biscuit' and 'carrot') or purely thematically/associatively-related (e.g., 'rabbit' and 'carrot').

Mani et al. (2012) investigated the parallel activation of phonological and semantic representations using a picture priming paradigm. Participants were presented with either a phono-semantic prime or unrelated prime picture in silence before hearing the target word. For example, they compared BOAT (phono-semantic picture prime)–'Hat (target word)!' with Boat (unrelated picture prime)–'Table (target word)!', and found that target recognition in 24-month olds was impaired (at chance) if participants saw the unrelated prime picture, but remained intact when participants saw the phono-semantic prime picture. The authors argue that these results demonstrate that, as with adults (Marslen-Wilson & Zwitserlood, 1989), spoken-word recognition during infancy involves cascaded and co-activation of phonological and semantic representations (i.e., seeing Boat leads to the activation of 'coat' which then pre-activates 'hat')[3].

In sum, IPL studies have demonstrated that infants by the age of two have formed adult-like phonological and semantic links in their lexicon, and that phonologically- and semantically-relevant information are retrieved during spoken-word recognition. In principle, it might seem possible to examine the *relative* potency of semantic and phonological information using two-picture tasks. For example, a 'target absent' design might name an absent object 'dog' in the presence of images of a cat and a door. Any relative preference for one of the pictures over the other might indicate the degree to which phonological vs. semantic/perceptual information drives looking behaviour. The relative timing of the eye fixations on the two pictures might also provide useful clues to the speed with which phonological and semantic information is activated. A tendency to fixate the door before the cat would point to ear-

[3]Note that since the target word was explicitly named, these results could be interpreted as the separate effects of phonological priming (i.e., seeing Boat activated 'coat') and semantic priming (i.e., 'coat' did not inhibit the target word 'Hat'), and may not necessarily be the result of cascaded activation of phonological and semantic representations'.

lier activation of phonological information compared to semantic information. However, in this two-picture IPL task, it is possible that toddlers show preferential fixation towards a phonological foil, not because of the activation of phonological information, but just because the semantic/perceptual picture (cat) does not match the word 'dog' (the door is the only other image on display). Inferring the activation of phonological information requires that the door is preferentially fixated *relative* to an *unrelated* image, e.g., a plate. Since there are only 2 pictures on display, the standard IPL task does not allow us to examine simultaneously the time course and competition between the activation and matching of phonological and semantic representations during spoken-word recognition.

1.5 Thesis Overview: Part I & Part II

The aim of this thesis is to examine how language mediates visual attention in 24- to 30-month-old toddlers. In Part I of the thesis, I will use the 'psycholinguistic' approach to investigate how 24- to 30-month-old toddlers process spoken words (see Figure 1.3). Specifically the time course and order in which phonological and semantic representations are activated, retrieved and recognised during spoken-word recognition. Moreover, individual differences of vocabulary development is pronounced at this age. We will look at how age group and vocabulary size may predict individual differences in the cognitive processes of spoken-word recognition, as reflected in language-mediated visual attention. Experiments 1 to 4 will compare the time course of the activation of phonological (cohort and rhyme) and semantic (taxonomic and thematic) representations during spoken-word recognition.

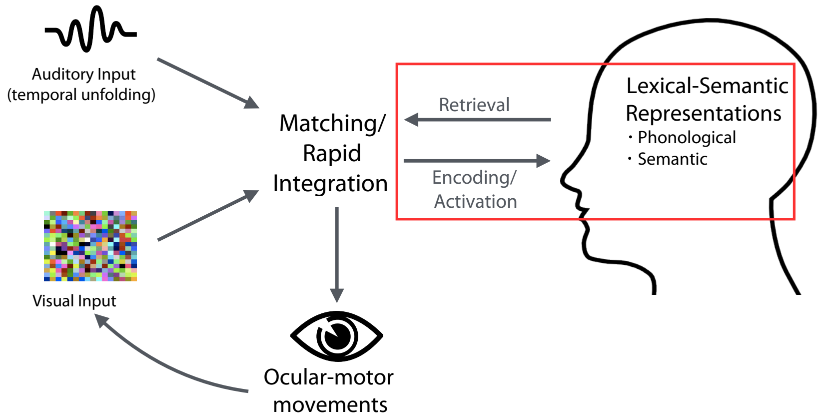

Figure 1.3. The 'psycholinguistic' approach. Part I of the thesis will investigate the time course and order in which different types of stored linguistic representations are activated during spoken-word recognition by adapting the adult four-picture visual world paradigm for infant testing.

In Part II of the thesis, I will use the 'visual search 'approach to investigate how semantics may drive visual selection in 24-month-old toddlers (see Figure 1.4). Specifically, how does semantics guide visual selective attention to the relevant information (e.g., target location and identity) over the irrelevant ones using a negative priming procedure. I will first review the existing literature on the negative priming effect in infants, children, and adults. I will then present Experiment 5 in which I investigate how labelling as a language attentional set can drive toddler's visual selective attention using the negative priming procedure. Specifically, by examining potential positive or negative after-effects of selectively attending a target location and/or identity, we could infer how top-down semantics interacts with bottom-up visual and auditory inputs: By target amplification or distractor inhibition, or both.

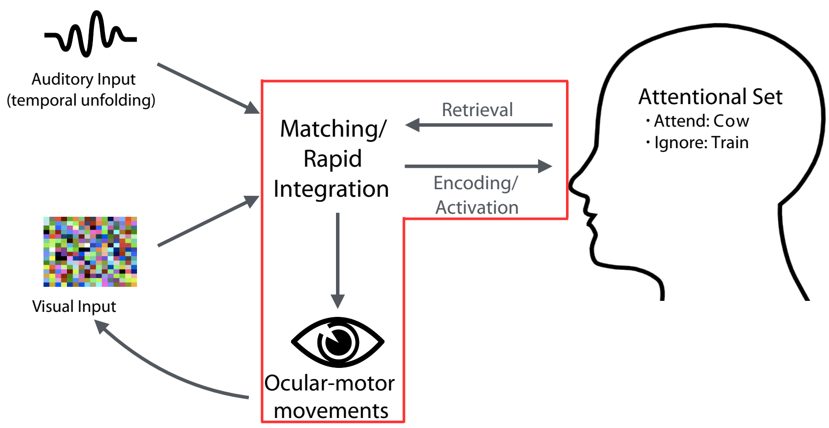

Figure 1.4. The 'visual search' approach. Part II of the thesis will investigate how an attentional set may drive visual selection using a negative priming procedure, specifically, the interaction and matching between the semantics of the attentional set and visual and auditory inputs.

Chapter 2

Equipments & Statistical Methods

2.1 Eye-tracker Setup

The Tobii TX300 automated eye-tracker was the primary equipment for data collection. Figure 2.1 shows the setup of the eye-tracking booth. Infants sat on their caregiver's lap approximately $65cm$ from the $23 - inch$ monitor of 1920 x 1080 screen resolution. The sampling rate was $120Hz$. The eye-tracker (underneath the monitor) uses infrared diodes to generate reflections on the participants' corneas. During data collection, the eye-tracker records the change of position of these reflections, inferring the direction of the participants' gazes. The study was run using PresentMate, a custom Matlab stimuli presentation framework based on Psychophysics Toolbox extensions (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). Communication with the Tobii eye-tracker was implemented using the Tobii Analytics Matlab binding based on Tobii Analytics SDK 3.0.

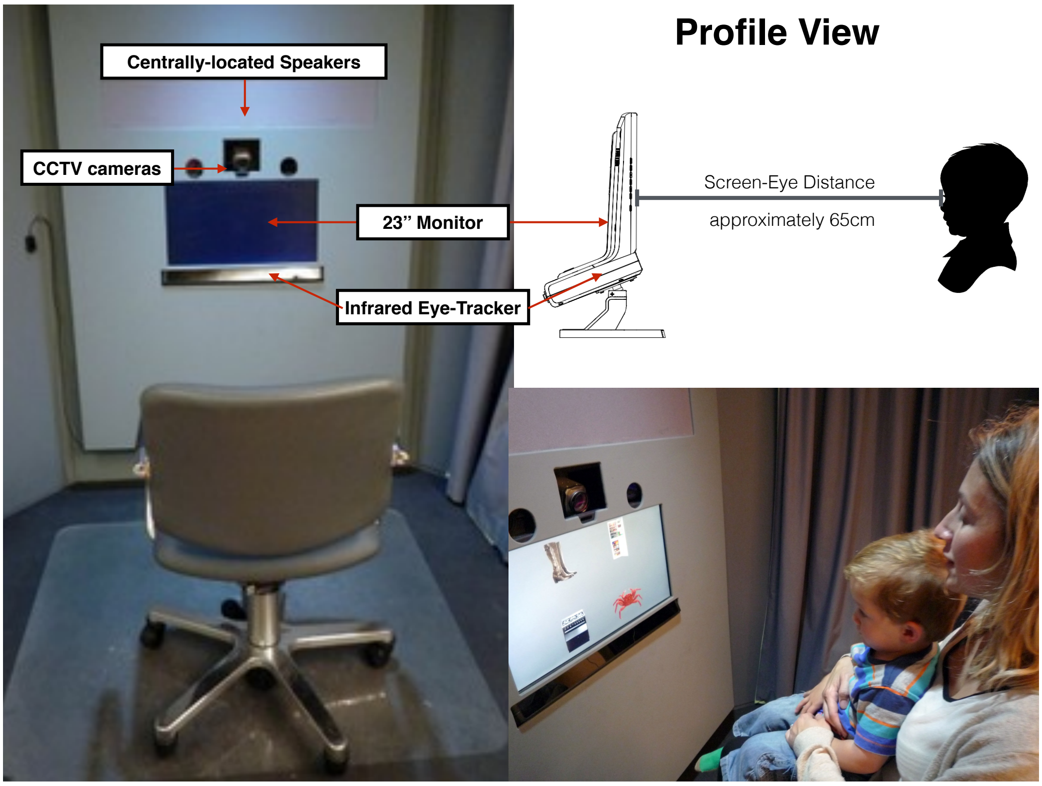

Figure 2.1. Eye-tracking setup.

At the beginning of each experiment, a nine-point calibration was performed. The calibration attention getter was a colourful beach ball. The background colour of the screen remained 50% grey throughout the experiment. Auditory stimuli were presented through a centrally located loudspeaker. In an adjacent room, the experimenter monitored the infant's behaviour through a centrally located video camera above the screen. To achieve good calibration, individual locations were recalibrated when necessary. After calibration, the experimenter initiated all trials by pressing a computer key, when the infant's attention was on the screen. Caregivers were instructed to keep their eyes shut, remain quiet and refrain from any interactions with infants during the experiment. Eye-tracking data was also processed in Matlab using custom code to extract fixation information. Minimum fixation duration was set to $100ms$ and a radius of $35pixels$.

2.2 Statistical Methods

It is commonplace in infant IPL studies to analyse eye-gaze data by aggregating total fixation times at the target (T) and distracter (D) to obtain a proportional measure of target picture fixation (P) after target word onset as shown in the following equation:

$$Prop_{Target} = T/(T + D) \tag{2.1}$$

Since there are just two pictures to fixate, significant deviations from chance (0.5) are taken as evidence of a systematic response to the target word[1]. This method, however, ignores the *time course* of fixations during a trial that can be highly informative. For example, a total proportion of 50% of target fixation might result from an increase from 0 to 100% of target looking, or a decrease from 100% to 0% target looking during the observed time window. Such timing differences have the potential to reveal the manner in which lexical representations are activated.

In contrast, adult VWP studies often aim to take into account more dy-

[1]Note that, in principle, *any* significant deviation from chance—positive or negative—constitutes a systematic response to the target word. The typical finding is that infants show a preference for the target picture. Some investigators also take account of looking prior to the onset of the target word in order to obtain a baseline preference for each picture. Other studies use difference measures between single longest looks at the two pictures or latency to disengage from the target or distracter pictures.

namic changes in eye fixations after target word onset. Post-naming fixations, usually $1000 - 2000ms$ after target word onset, are usually divided into finer timebins of equal duration, e.g. $50ms$ or $100ms$ each. In early studies (e.g. Allopenna et al., 1998; Huettig & McQueen, 2007), participants' preference for a target-related distractor over an unrelated distractor in each time bin is summarized by a 'preference ratio'. The preference ratio in each timebin can be compared to chance (0.5) in a one-sample t-test. A ratio significantly greater than 0.5 indicates a stronger preference for the target-related distractor over the unrelated distractor in a particular timebin. Growth of fixation preference is indexed by an increase in the number of significant t-tests across all timebins. While Bonferroni corrections can be applied to counteract the problem of multiple t-test comparisons, this approach is often too conservative for studies with strong hypotheses. Another limitation with this method of analysis is that eye-tracking data, like other response data, is binomial: a participant either looked or did not look in each frame recorded by the eye-tracker (for a $120Hz$ sampling rate, duration of one time frame is $8.3ms$). As a result, eye-tracking data is unlikely to be normally distributed, especially in small timebins. Moreover, t-test analyses do not allow inspection of interactions of effects, such as the effect of Condition and Age, or to account for individual variability among participants.

To address these issues, recent adult VWP and infant IPL studies have begun to analyse eye-tracking data using generalized-linear mixed models (e.g. Barr, 2008; Law II & Edwards, 2014; Von Holzen & Mani, 2012). In the current study, we analysed eye fixations using logistic mixed effects models with the R package glmmPQL, which uses penalised quasi-likelihood estimation. As the data follows a curvy trend with two peaks, we modelled time-course data using third-order (cubic) orthogonal polynomials (see chapter 3.3.3 in (Mirman, 2014) for the advantages of using orthogonal polynomials over natural polynomials). Note that due to centering, the orthogonalised intercept term corresponds to the overall average, rather than the baseline of the measurement. The model has two levels: Level 1 examines how individuals fixation patterns change over time (linear), time^2 (quadratic) and time^3 (cubic). Level 2 examines the effects of picture role, age group or vocabulary size on individual patterns of fixation. As an increased amount of attention to one object will inevitably lead to a decreased amount of attention to the other object(s) within the same timebin, we account for such dependence by including picture co-occurrence in each timebin nested under participant as random effects in the model.

The raw fixation data is initially organised by time frame . The probability (p) of a participant fixating an area of interest (AOI) such as the target picture during a particular timebin, say 100ms, is determined by counting the number of frames in which the participant looked at the AOI (S) divided by the total number of frames recorded in the timebin (N), i.e., $p = S/N$. The probability of a participant not fixating the AOI (q) is then just $q = 1p$. Binomial logistic models estimate the log of the odds ratio for fixating and not fixating the AOI, i.e., $log(p/q)$. It is important to note that gaze data, like other types of time-series data, can be autocorrelated, e.g., gaze at time point 2 may be dependent on gaze at time point 1. To remove the autocorrelation between the raw gaze data points, the data is aggregated in each timebin for each picture role and participant. To illustrate, assume 2 trials are recorded from a participant. Each trial lasts $1200ms$ and is divided into twelve 100ms timebins for growth curve analysis. The number of frames recorded (N) in each 100ms timebin in each trial would be $100ms/8.3ms = 12$ frames. The aggregated N would then be 2 trials $\times$ 12 frames = 24 frames. Suppose the participant fixated an AOI, such as the target picture, for 5 frames in timebin 1 during the first trial, and 10 frames in timebin 1 during the second trial. The aggregated S for timebin 1 would be 5 frames + 10 frames = 15 frames. The probability of fixating the AOI in timebin 1 is $p = 15/24 = 0.625$ and the log odds ration $log(p/q) = log(0.625/0.375) = log(1.67)$.

Part I

Retrieval of Phonological and Semantic Representations during Spoken-Word Recognition

Chapter 3

Experiment 1: Target vs. Phonological vs. Taxonomic

3.1 Introduction

Experiment 1 is a first attempt to adapt the four-picture Visual World Paradigm (VWP) for infant testing. As shown in Figure 3.1, each trial includes four pictures: a target (e.g. penguin), the referent of the auditory target word; a 'phonological' distractor with the same onset consonant as the target word (e.g. pear); a 'taxonomic' distractor belonging to the same taxonomic category as the target word (e.g. tiger); and an unrelated distractor that is unrelated to the target word and the other distractors (e.g. cot). The experiment is based on Huettig & McQueen (2007) insofar as we investigate the time course of eye-fixations to the phonological and taxonomic distractors as an index of the activation of phonological and semantic representations related to the target word. However, while Huettig & McQueen (2007) used a target-absent[1] scenario, we include the target picture to establish that infants can readily identify a target referent in a four-picture array upon hearing a target word and to investigate whether a target-present design is sensitive enough to capture the time course of the activation of phonological and taxonomic representations, as indexed by fixations of the phonological and taxonomic distractors.

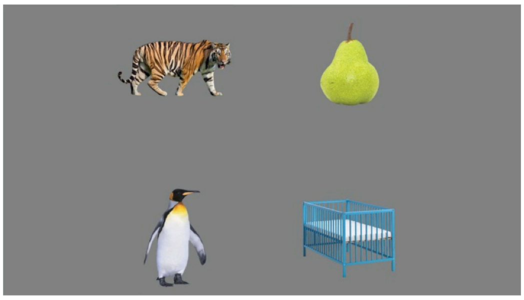

Figure 3.1. Example of the four-picture array. The target is ‘penguin, the phonological distractor is ‘pear, the taxonomic distractor is ‘tiger, and the unrelated distractor is ‘cot.

Adult VWP studies have demonstrated that participants not only show a preference for the target picture, but also for target-related distractors (Allopenna et al., 1998; Huettig & Altmann, 2005; Mirman & Graziano, 2012). Based on these findings, we predicted that both the 24- and 30-months old participants in this experiment would preferentially fixate the target object over the unrelated distractor after target word onset, demonstrating tar-

[1]Huettig & McQueen (2007) exclude the target referent from the display in their critical trials.

get word recognition. Moreover, we predicted that they would fixate the phonological distractor more than the unrelated distractor early in the time course—an early phonological preference, and the taxonomic distractor more than the unrelated distractor later in the time course—a late taxonomic preference. Any lack of preference for the target and/or target-related object(s) would indicate that the four-picture setup failed to measure mental processes related to spoken-word recognition in an infant population. Finally, we explored how age might modulate fixation patterns in a four-picture setup by comparing the fixation preferences of 24- and 30-month olds—a period of dramatic vocabulary growth, and possible consolidation and organisation of the lexical-semantic system.

3.2 Method

3.2.1 Participants

Twenty-three 24-months olds ($M_{age} = 24.24$, age range $= 23.4 - 24.96$, Male $= 16$, Female $= 7$) and twenty-three 30-months olds ($M_{age} = 29.88$, age range $= 29.4 - 30.48$, Male $= 10$, Female $= 13$) were recruited from British English monolingual households. Eight additional participants were excluded from analysis: six owing to fussiness in the experiment and two as a result of visual problems (had to wear glasses) and clinically diagnosed speech delay.

3.2.2 Design

Each participant saw a total of 12 trials, which were presented in a computer-randomised order. There were four lists of test stimuli (see Tables A2 to A9 in Appendix A). Participants were randomly assigned to one of the lists. Figure 3.2 shows the timeline of a trial. At the beginning of each trial, an audio-visual attention getter appeared in the middle of the screen for $1000ms$. The target, phonological distractor, taxonomic distractor and unrelated distractor then appeared on the screen for a total duration of $9000ms$. The onset of the auditory label occurred $4000ms$ after the onset of the visual stimuli. This timing permitted the infants to view the pictures before ($4000ms$) and after target onset ($5000ms$). In a typical two-picture infant study, infants are given approximately $2500ms$ to view the pictures before target word onset, and $2500ms$ to respond after target word onset.

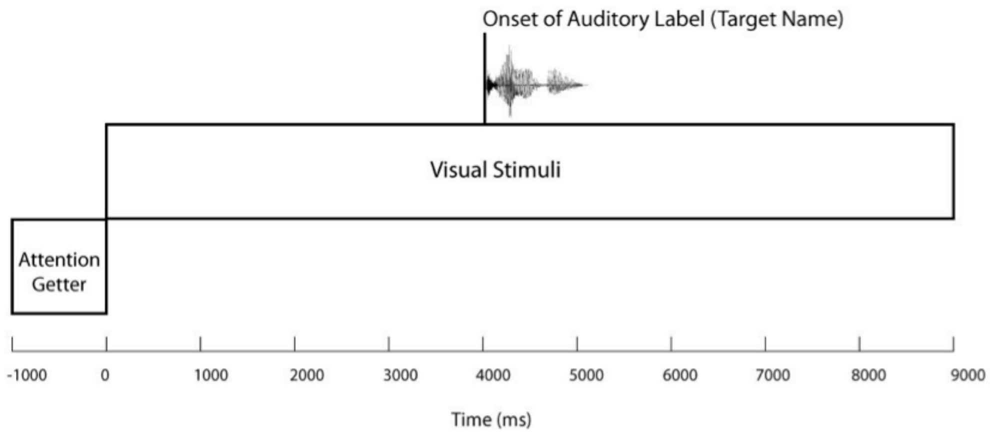

Figure 3.2. Experiment 1 trial timeline. Each trial began with a $1000ms$ attention getter. The visual stimuli appeared on screen from 0 to $9000ms$. Onset of the auditory label of the target word was always at $4000ms$.

3.2.3 Stimuli

Forty-eight words, ranging from one to four syllables, were yoked [2] to form four sets of twelve quadruples of words (see Table A1 in Appendix A). There was no repetition of any stimuli within the same yoke set. Across the four yoke sets, each word served as the target, phonological distractor, taxonomic distractor and unrelated distractor. The target was named. The phonological distractor shared the same onset consonant with the target word. The taxonomic distractor belonged to the same taxonomic category as the target word. The unrelated distractor was unrelated to the target word, phonological distractor and taxonomic distractor. Pictures in each set were non-associated according to the University of South Florida word association norms (D. L. Nelson et al., 1998), and were generally visually dissimilar (e.g., penguin, pear, tiger and cot). The combination of the four pictures differed across the four yoke sets so that picture roles (i.e., target, phonological distractor, taxonomic distractor, and unrelated distractor) were counterbalanced across yoke sets (and participants). Yoke sets 14 were then organised into Lists 14. Each list had two versions, a and b, which counterbalanced for picture location (see further details in the section on Picture Location). Therefore, there were in total eight lists (see Tables A2 to A9 in Appendix

[2] The yoked control procedure was first used in operant conditioning experiments with animals. In a typical operant conditioning experiment, the same reinforcement (e.g. food) is yoked (paired up) with either the experimental contingency (e.g. food delivery is contingent on lever pressing) or control contingency (e.g. food delivery is not contingent on lever pressing). In a typical two-picture infant IPL study, yoking typically refers to the counterbalancing of the role of the picture stimulus (e.g., once as target, once as distractor).

A).

Amongst the 48 pictures and target words, 40 were chosen from the Oxford Communicative Development Inventory (OCDI) (Hamilton et al., 2000), while eight of them were extra word norm data that we collected alongside the OCDI since 2012. Extra words were included because a four-picture setup requires double the number of stimuli compared to a two-picture study. Target words and pictures in the test trials were chosen based on the criterion that at least 60% of 24-month-olds were reported to understand each word.

Visual Stimuli

Realistic photographic representations were used. Objects were edited out of their original background, and placed in the centre of a 9.53 x 9.53cm (50% grey colour) background using Adobe Photoshop. The four square images (i.e the AOIs of eye-gaze measurement), were located in the upper left, upper right, lower left and lower right corners of an invisible square, of a total area of 28.58 x 28.58cm (23.7°), with a distance of 9.53cm (8.34°) separating the pictures horizontally and vertically.

In each set of four images, each object had a different main colour(s). Objects without a typical colour were assigned a colour that had not been used within the same set, e.g. a car does not have a typical colour. However, objects with a typical colour(s) were always represented in their typical colour(s), e.g. a banana is yellow. In order to counterbalance for colour within sets and across lists, a different photographic representation was used for each word in each list. The heads of all animals and the front of all vehicles faced towards the middle to eliminate the possibility of image orientation or head direction as a cue. Since objects that move in real life may attract more attention, we counterbalanced for movement: in each list, an equal number of naturally moving objects (four animals and two vehicles each) served as the target, phonological distractor, categorical distractor and unrelated distractor.

Auditory Stimuli

A Southern British English speaker recorded auditory labels of target words in child-directed speech. Mean duration of target words was $586ms$. Background noises, and head and tail clicks were removed using GoldWave.

Picture Location

Firstly, the location of the target was counterbalanced. An equal number of targets appeared in each of the four locations in each list. Secondly, the locations of the non-targets were counterbalanced. Equal numbers of phonological, taxonomic and unrelated distractors were placed left or right, above or below, and diagonal to the target in each list.

3.2.4 Procedure

Infants sat on their caregiver's lap approximately $65cm$ from a Tobii TX 300 eye tracker and a 23-inch screen of 1920 x 1080 screen resolution. The sampling rate was $120Hz$. After calibration, infants were shown 12 trials. The experimenter initiated all trials by pressing a computer key, when the infant's attention was on the screen.

3.3 Results

Twenty-four-month-olds yielded a total of 221 out of 276 trials available for analysis (on average 10 out of 12 trials per participant). Six trials (2%) did not provide any data due to the infant not looking. Forty-nine trials (18%) were excluded due to unfamiliarity with pictures or words used, as reported by parents. Thirty-month-olds yielded a total of 253 out of 276 trials available for analysis (on average 11 out of 12 trials per participant). Eighteen trials (7%) were excluded due to unfamiliarity with the pictures or words used. A further five trials (2%) did not provide any data due to the infant not looking during the entire trial or after target word onset. The same pattern of results were obtained irrespective of the inclusion of words unknown to the infant, as measured by the OCDI. However, only results for words known to the infant are included as these give the clearest findings.

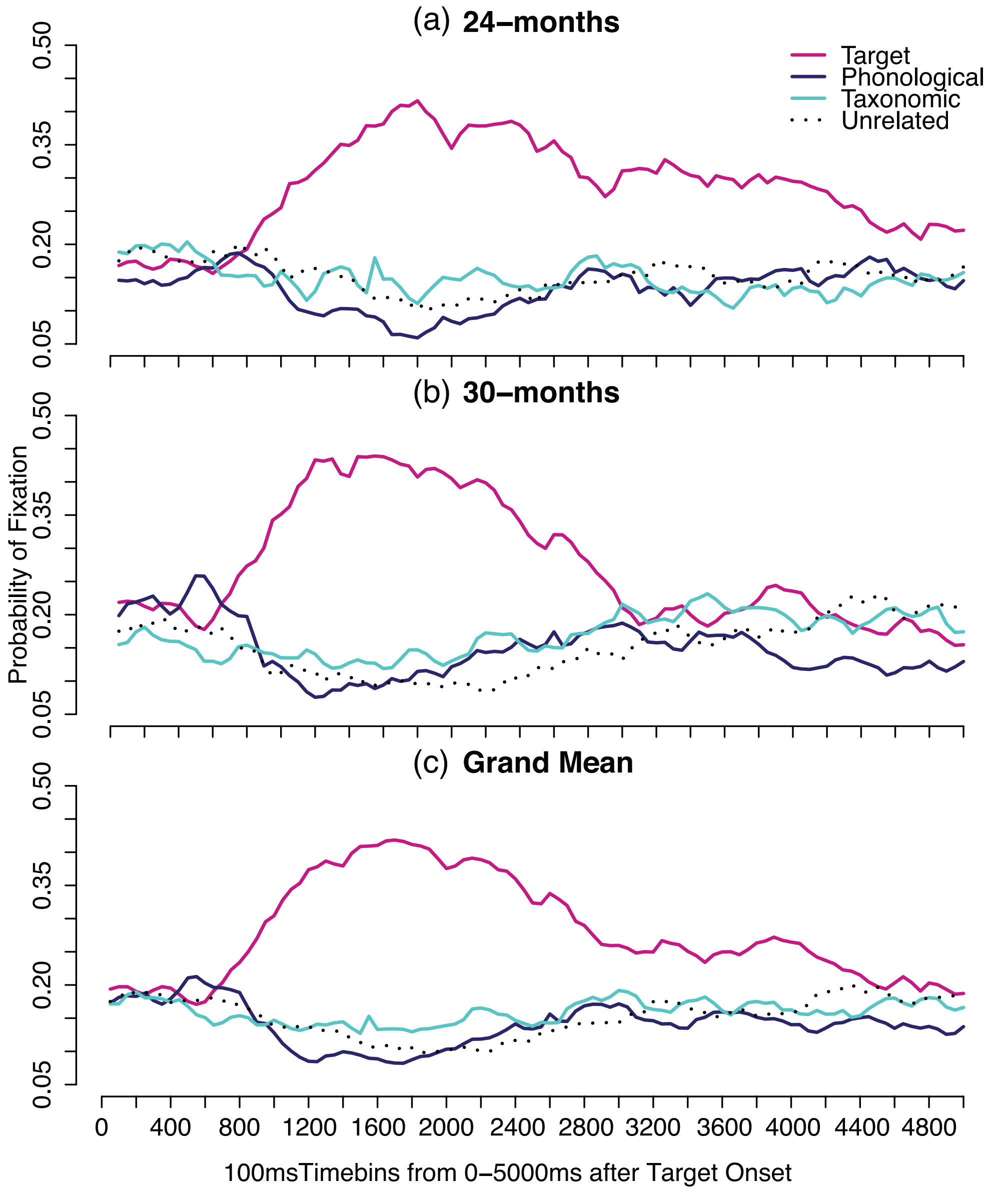

Figure 3.3. Experiment 1: Time course of fixation from onset of the auditory label of the target: (a) 24-month-olds, (b) 30-month-olds and c) grand mean of both age groups.

Figure 3.3 shows the averaged time course of fixation from onset of the auditory label of the target in 24- and 30-month-olds, and the grand mean of both age groups (top, middle and bottom panels respectively). To capture target-word driven eye-movements in our analysis, we defined a time window for analysis based on the grand mean of the data. Following (Barr, 2008), we determined the starting point of our analysis by locating the breakpoint at which one of the curves showed apparent change. As seen in the bottom panel of Figure 3.3, the earliest break was at around $400ms$ after target onset. Fixations for the target peaked at around $1600ms$, and gradually returned to baseline level by the end of the trial. Visual inspection of the grand mean suggests that a time window of $1200ms$ from 400 to $1600ms$ after target word onset is sufficient to capture both age groups fixation patterns.

3.3.1 Growth Curve Analysis

The overall time course of fixations was captured by third-order orthogonal polynomials with Level 2 fixed effects of picture role (target vs. phonological vs. taxonomic vs. unrelated) on all time terms, age group (24- vs. 30-months) on the intercept and slope terms, and picture co-occurrence in each timebin nested under participant random effects on the intercept term. The unrelated distractor and 30-month-old age group were treated as the baseline in the model, and relative parameters were estimated for the target, phonological distractor, taxonomic distractor, and 24-month-old participants. Fixations outside of the AOIs, e.g., blank space, were excluded from analysis.

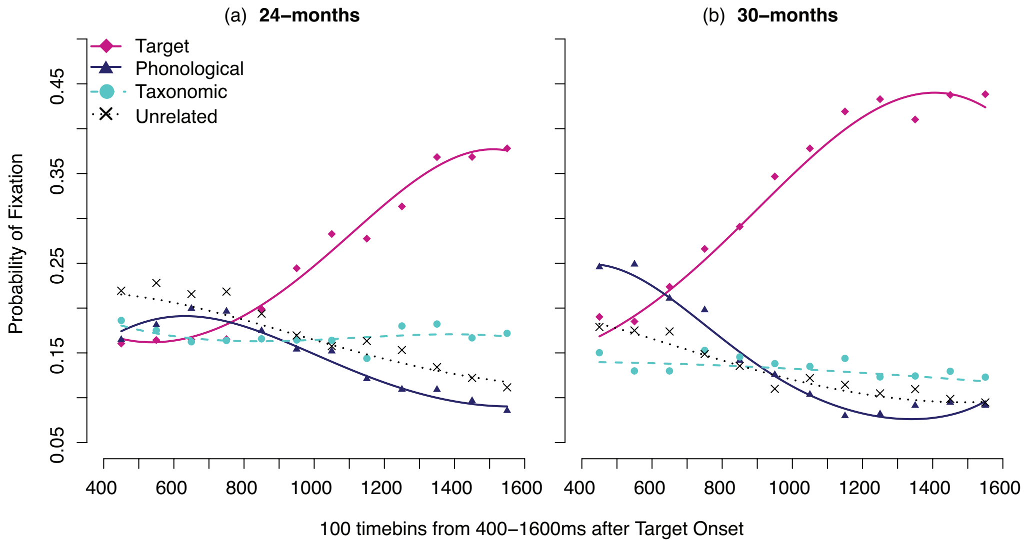

Figure 3.4. Experiment 1. Growth curve analysis of (a) 24-month-old and (b) 30-month-old participants. Data shown in points, the model shown in lines.

Figure 3.4 shows the aggregated data as points and the fitted model as lines for each picture role and age group. The graph indicates that both age groups had greater preference for the target than the distractors. Preferences among the related and unrelated distractors are less clear cut.

Table 3.1. Experiment 1: Growth Curve Analysis. The unrelated distractor and 30-month-old age group were treated as baseline in the model, relative parameters were estimated for the target, phonological distractor, taxonomic distractor and 24-month-old age group.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Target	Intercept	1.19 (0.07)	18.27	<.001***
	Linear	2.45 (0.23)	10.75	<.0001***
	Quadratic	-0.26 (0.17)	-1.56	.1193
	Cubic	-0.27 (0.17)	-1.64	.102
Phonological	Intercept	0.04 (0.08)	0.49	.6210
	Linear	-0.78 (0.26)	-3.02	.0026**
	Quadratic	0.10 (0.19)	0.51	.607
	Cubic	0.24 (0.18)	1.30	.1942
Taxonomic	Intercept	0.05 (0.07)	0.70	.4862
	Linear	0.70 (0.25)	2.75	.0061**
	Quadratic	-0.33 (0.18)	-0.18	.8559
	Cubic	-0.10 (0.18)	-0.54	.5875
24-month-olds	Intercept	0.31 (0.12)	2.68	.0103*
	Linear	0.08 (0.26)	0.30	.7642
Target*24-month-olds	Intercept	-0.65 (0.10)	-6.679	<.001***
	Linear	-0.1 (0.33)	-0.31	.7569
Phonological*24-month-olds	Intercept	-0.22 (0.11)	-2	.0453*
	Linear	0.62 (0.38)	1.65	.1001
Taxonomic*24-month-olds	Intercept	-0.01 (0.10)	-0.11	.9122
	Linear	0.11 (0.36)	0.30	.7638
				$***p<.001, **p<.01, *p<.05$

Table 3.1 summarises the results of the growth curve analysis. There was a significant effect of Target picture. The significant intercept term indicates that, overall, participants fixated the target reliably more than the unrelated distractor. Moreover, the significant linear term shows that the growth of target fixation followed a steeper linear slope than that of the unrelated distractor. There was also a significant effect of age group. The significant intercept term for age (24-month-olds) indicates that regardless of picture role, 24-month-olds spent more time fixating the pictures than did the 30-

month-olds. However, the significant negative interaction of target looking with age (Target*24-month-olds) on the intercept term indicates that, despite generally having spent more time looking at the four-picture display, 24-month-olds fixated the target less than 30-month-olds.

Contrary to our predictions, participants did not fixate the phonological distractor more than the unrelated distractor. The non-significant intercept term indicates that participants overall spent similar amounts of time fixating the phonological and unrelated distractors. However, the significant negative linear term indicates that phonological distractor fixation decreased at a faster rate than that of the unrelated distractor. There was also a significant interaction between phonological distractor looking and age (Phonological*24-month-olds). The significant negative intercept term indicates that 24-month-olds fixated the phonological distractor less than 30-month-olds. Similarly, the non-significant intercept term for the taxonomic distractor indicates that participants spent similar amounts of time fixating the taxonomic and unrelated distractors. However, the significant linear term indicates that taxonomic distractor fixation decreased at a slower rate than that of the unrelated distractor. There was no interaction between taxonomic looking and age (Taxonomic*24-month-olds).

3.3.2 Vocabulary Analysis

For the twenty-three 24-month-olds included in the analysis, the averaged OCDI receptive score was 430 words ($SD = 80$), and the averaged OCDI expressive score was 315 ($SD = 119$). For the twenty-three 30-month-olds included in the analysis, the averaged OCDI receptive score was 491 ($SD = 38$), and the averaged OCDI expressive score was 452 ($SD = 68$). As vocabulary score was negatively skewed, the Mann-Whitney U test was used for the following comparisons. Twenty-four-month-olds had a significantly lower OCDI receptive score ($U = 141, p = .007$) and expressive score ($U = 81, p < .001$) than 30-month-olds. Separate bivariate correlation tests indicate no correlations between receptive vocabulary size and averaged time spent fixating the target, phonological distractor, taxonomic distractor and unrelated distractor during 400–1600ms after target word onset (all $ps > .1$). Similarly, there were no correlations between expressive vocabulary score and averaged time spent fixating the target, phonological distractor, taxonomic distractor and unrelated distractor.

3.3.3 Picture Location

We examined whether picture location had an effect on target fixation. A 2 (age group) x 4 (location: upper left, upper right, lower left, lower right) mixed analysis of variance yielded no significant effect of age group ($F(1, 44) = 2.36, p = .1318$), location ($F(3, 124) = 0.81, p = .4894$), or interaction of age group*location ($F(3, 124) = 0.42, p = .7420$). The results suggest that participants showed similar degrees of target preference at all four locations.

3.3.4 Discussion

Experiment 1 successfully demonstrated that a four-picture target-present scenario can capture infants' preferences for named target objects. Both 24- and 30-month-old participants demonstrated a strong preference for the target object over the unrelated distractor in response to the auditory label (see the fixed effect of target in Table 3.1). Moreover, there were age-group differences in infants' fixation patterns. Despite spending overall more time looking at the four-picture display, 24-month-olds fixated the target less than 30-month-olds (see the fixed effect of 24-month olds and target*24-month olds in Table 3.1). Picture location had no effect on target preferences.

Overall, our infant participants spent similar amounts of time fixating the phonological and unrelated distractors. However, the significant linear component suggests that fixation towards the phonological and unrelated distractors followed different growth trends over the course of the trial. The interaction of phonological fixation and age group indicates that 30-month-olds fixated the phonological distractor more than 24-month-olds (see the fixed effect of phonological and phonological*24-month olds in Table 3.1). Similarly, participants spent similar amounts of time fixating the taxonomic and unrelated distractors. However, the significant linear component indicates that fixations of taxonomic and unrelated distractors followed different growth trends (see the fixed effect of taxonomic in Table 3.1).

To conclude, Experiment 1 provides tentative evidence that participants treated the related and unrelated distractors differently. However, it is also evident that the majority of participants' attention was drawn to the target upon hearing the target label, leaving little room for the phonological and taxonomic distractors to play any substantial role in mediating infants' visual preference.

Chapter 4

Experiment 2: Phonological vs. Taxonomic

4.1 Introduction

To maximise fixations towards the phonological and taxonomic distractors, we presented participants with a target-absent four-picture display including a phonological distractor, a taxonomic distractor, and two unrelated distractors. Visual stimuli in Experiment 2 were yoked *within* participants for more precise counterbalancing. As in Experiment 1, participants were predicted to show an early phonological preference and a late taxonomic preference. To persuade toddlers to search for a picture related to the target label, 27% of the trials contained an image of the object of that was labelled.

4.2 Method

4.2.1 Participants

Twenty-four 24-month-olds (M_{age} = 24.24, age range = 23.28-25.44, Male = 15, Female = 9) and twenty-four 30-month-olds (M_{age} = 29.88, age range = 29.4-30.96, Male = 10, Female = 14) recruited from British English monolingual households were included in the analysis. Nine additional participants were excluded from analysis due to fussiness. Another six additional participants were excluded from analysis due to having too few trials (less than one-third of test trials, i.e., eight trials) in which their caregivers reported understanding of the words used.

4.2.2 Design

Each participant saw a total of 24 target-absent test trials and 9 target-present filler trials, which were presented in a pseudo-random order in four blocks. The filler trials served to maintain the participants' attention, as infants at this age can easily get frustrated if the target word never matches any of the pictures. Participants were randomly assigned to one of four lists (see Tables B2 to B5 in Appendix B). The four lists contained the same trials but served to counterbalance for block order and picture location. Each list started with a filler trial, which was the same trial for all 4 lists. In each block, there was always a filler trial before the first test trial and after the second test trial. As shown in Figure 4.1, there was an attention getter at the beginning of each trial. The four pictures appeared on the screen for a total of 8000ms. The target word onset, e.g. 'bee', was always at 4000ms, and was preceded by a prompt phrase 'Look at the'. Target word onset thus divided the trial into two phases, a 4000ms pre-naming phase and 4000ms post-naming phase.

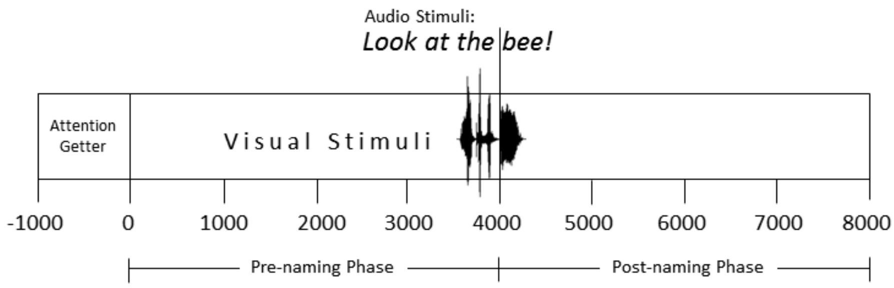

Figure 4.1. Experiment 2 trial timeline. Each trial began with a 1000ms attention getter. The visual stimuli appeared for a total of 8000ms. Onset of the auditory label of the target word was always at 4000ms.

4.2.3 Stimuli

The stimuli were six sets of four pictures (total 24 pictures), and 24 target words (presented as an audio label). As shown in Table B1 in Appendix B, each of the six sets of pictures were repeated four times, and each time they were paired with a different target word. As a result, each picture in each set served four roles: once as a phonological distractor to the target word, once as a taxonomic distractor to the target word, and twice as an unrelated distractor. As in Experiment 1, the phonological distractor depicts a picture that, if spoken, starts with the same onset consonant as the target word. The taxonomic distractor is in the same taxonomic category as the target. The unrelated distractors were unrelated to each other, and unrelated to the target, phonological distractor and taxonomic distractor. Pictures in each set (e.g., bus, cat, sandwich and dress) were visually dissimilar and unassociated according to the University of South Florida Free Association Norms (D. L. Nelson et al., 1998).

Among the 48 pictures and target words (ranging from one to four syllables), 40 were chosen from the OCDI, while eight of them were extra word norm data that we collected alongside the OCDI since 2012. Target words and pictures in the test trials were chosen based on the criterion that at least 60% of 24-month-olds were reported to understand the word. There were in total eight categories: animal, clothing, electrical appliance, food, furniture, toiletries, toys, and vehicle.

Visual Stimuli

Realistic photographic representations of the objects were edited in exactly the same fashion as in Experiment 1.

Auditory Stimuli

The auditory stimuli were produced in the same way as in Experiment 1 except that a prompt phrase preceded the target word, e.g., "Look at the bee!". Mean duration of target words was $602ms$.

Picture Location

Picture location was counterbalanced both within and between participants. Within participants, each picture (e.g., car) appeared at each of the four screen locations once across the four blocks. Between participants, pictures in each trial appeared at all four locations for an equal number of times. Location of the pictures by role (i.e., the phonological distractor, taxonomic distractor, unrelated distractor 1 and unrelated distractor 2) was also counterbalanced both within and between participants. Within participants, each (picture) role appeared at either the left or right side of the screen an equal number of times (i.e., 24 times on the left and 24 times on the right). Between participants, the (picture) roles in each trial were counterbalanced, and appeared at all four locations on the screen an equal number of times. There were at least 2 trials and a filler trial between repetitions of any picture set.

4.2.4 Procedure

The procedure was identical to Experiment 1.

4.3 Results

Overall, 24-month-olds contributed 447 out of 576 trials (on average 19 out of 24 trials per participant) for analysis. One-hundred and ten trials (19%) were excluded because of unfamiliarity with pictures or words used. Nine trials (2%) were excluded due to zero post-naming looking time. A further 10 trials (2%) did not provide any data due to the infant not looking during the entire trial. Thirty-month-olds contributed 513 out of 576 trials (on average 21 out of 24 trials per participant) for analysis. Forty trials (7%)

were excluded due to unfamiliarity with pictures or words used. Nine trials (2%) were excluded due to zero post-naming looking time. A further 14 trials (2%) did not provide any data due to the infant not looking during the entire trial. The same pattern of results were obtained irrespective of the inclusion of words unknown to the infant. However, only results for the words known to the infant are included as these give the clearest findings.

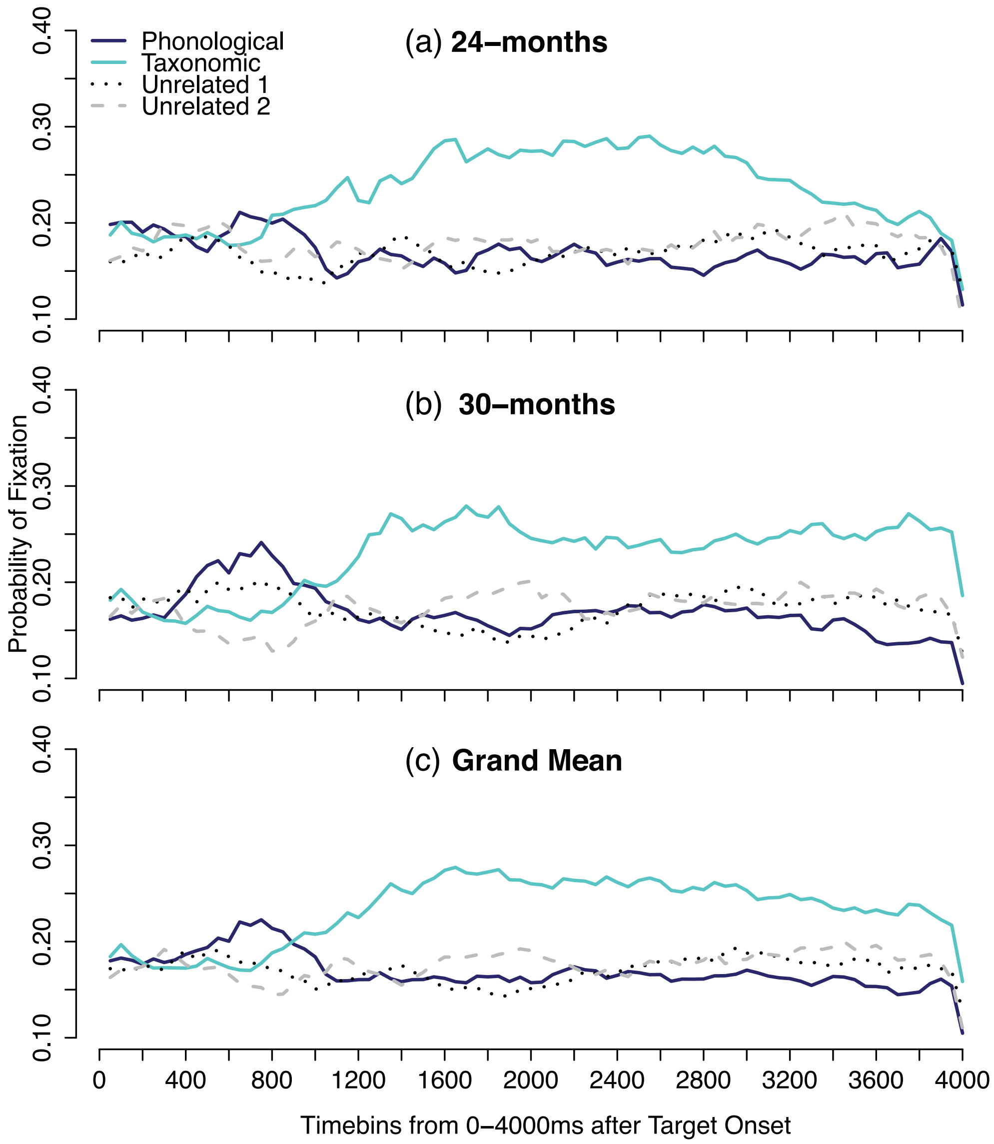

Figure 4.2. Experiment 2: Time course of fixation from onset of the auditory label of the target in (a) 24-month-olds, (b) 30-month-olds, and (c) grand mean of both age groups.

4.3.1 Growth Curve Analysis

Figure 4.2 shows the averaged time course of fixation from target word onset in 24- and 30-month-olds, and the grand mean of both age groups. We determined the starting point for analysis by locating the breakpoint at which one of the curves showed apparent change. As seen in the bottom panel of Figure 4.2, the earliest break was at around 330ms after target onset. Fixations for the four objects became approximately asymptotic from 1500ms to the end of the trial. A time window of 1200ms from 330 to 1530ms after target word onset thus captures both age groups fixation patterns. Preference for Unrelated Distractors 1 and 2 during the period 3301530ms after target word onset were at chance for 24-month-olds ($M_{difference} = 0.01, t(23) = 0.602, p = .553$) and 30-month-olds ($M_{difference} = 0.03, t(23) = 1.515, p = .143$). For simplicity, we use an average of Unrelated Distractors 1 and 2 in the following analyses.

The time course data was modelled using third-order orthogonal polynomials with fixed effects of picture role (phonological vs. taxonomic vs. unrelated) on all time terms, age group (24- vs. 30-months) on the intercept and linear terms, and picture co-occurrence in each timebin nested under participant random effects on the intercept and slope terms. The unrelated distractor and the 30-month-old age group were treated as the baseline in the model, and relative parameters were estimated for the phonological and taxonomic distractors, and the 24-month-old age group.

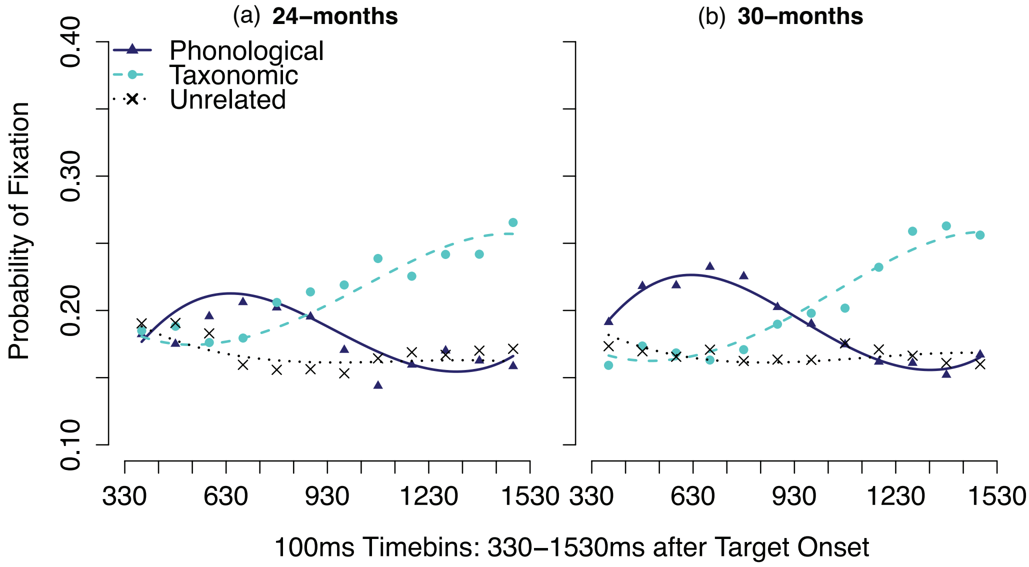

Figure 4.3. Experiment 2: Growth curve analysis of (a) 24-month-old and (b) 30-month-old participants. Data shown as points, the model shown as lines.

Figure 4.3 shows the data in points and the model in lines. The data points indicate that participants in both age groups fixated the phonological distractor more than the unrelated distractors earlier in the time course, and fixated the taxonomic distractor more than the unrelated distractors later in the time course. Table 4.1 summarises the results of the statistical model. For the phonological distractor, the significant intercept term shows that participants spent more time fixating the phonological distractor than the unrelated distractor. The significant linear, quadratic and cubic terms indicate that fixations towards the phonological and unrelated distractors followed different trajectories: phonological distractor fixation peaked shortly after target word onset, while fixations towards the unrelated distractor remained relatively flat. There was no reliable interaction of preference for the phonological distractor with age (Phonological*24-month-olds).

There was also a systematic preference to fixate the taxonomic distractor. The significant intercept term indicates that participants spent more time fixating the taxonomic distractor than the unrelated distractor. The significant linear term confirms that fixations towards the taxonomic distractor gradually increased during the time course while the slope of the unrelated distractor remained relatively flat. There was no reliable interaction of preference for the taxonomic distractor with age (Taxonomic*24-month-olds).

Table 4.1. Experiment 2: Growth Curve Analysis by Age Group. The unrelated distractor and 30-month-old age group were treated as baseline in the model, relative parameters were estimated for the phonological distractor, taxonomic distractor and 24-month-old age group.

Fixed Effects	**Model Terms**	**Est. (SE)**	**t**	**p**
Phonological	Intercept	0.15 (0.04)	4.02	<.001***
	Linear	-0.44 (0.13)	-3.37	<.001***
	Quadratic	-0.25 (0.1)	-2.65	.0082**
	Cubic	0.33 (0.1)	3.50	<.001***
Taxonomic	Intercept	0.23 (0.04)	6.21	<.001***
	Linear	0.78 (0.13)	6.13	<.001***
	Quadratic	-0.03 (0.09)	-0.28	.7819
	Cubic	-0.08 (0.09)	-0.82	.4112
24-month-olds	Intercept	-0.002 (0.05)	-0.05	.9618
	Linear	-0.10 (0.14)	-0.71	.4752
Phonological*24-month-olds	Intercept	-0.05 (0.06)	-0.86	.3908
	Linear	0.22 (0.19)	1.15	.2493
Taxonomic*24-month-olds	Intercept	0.05 (0.05)	0.88	.3766
	Linear	-0.02 (0.19)	-0.10	.9299
		$***p<.001, **p<.01, *p<.05$		

To compare the time course of phonological and taxonomic fixations, we relevelled the same model using the phonological distractor as the baseline measurement. The significant intercept term indicates that, overall, toddlers fixated the taxonomic distractor more than the phonological distractor (Estimates = 0.08(0.04), $t = 2.21, p = .0276$). More importantly, phonological fixation peaked before taxonomic fixation. The significant linear (Estimates = 1.22(0.13), $t = 9.67, p < .001$), quadratic (Estimates = 0.23 (0.09), $t = 2.46, p = .014$) and cubic terms (Estimates = 0.411 (0.09), $t = 4.47, p < .001$) confirm that the growth trend of taxonomic fixation was significantly different from that of phonological fixation. As seen in Figure 4.4, if we remove the significant linear, quadratic and cubic terms for picture role (see chapter 4.5 of Mirman, 2014), the reduced model (in grey) would predict no differences between the time course of phonological and taxonomic fixations.

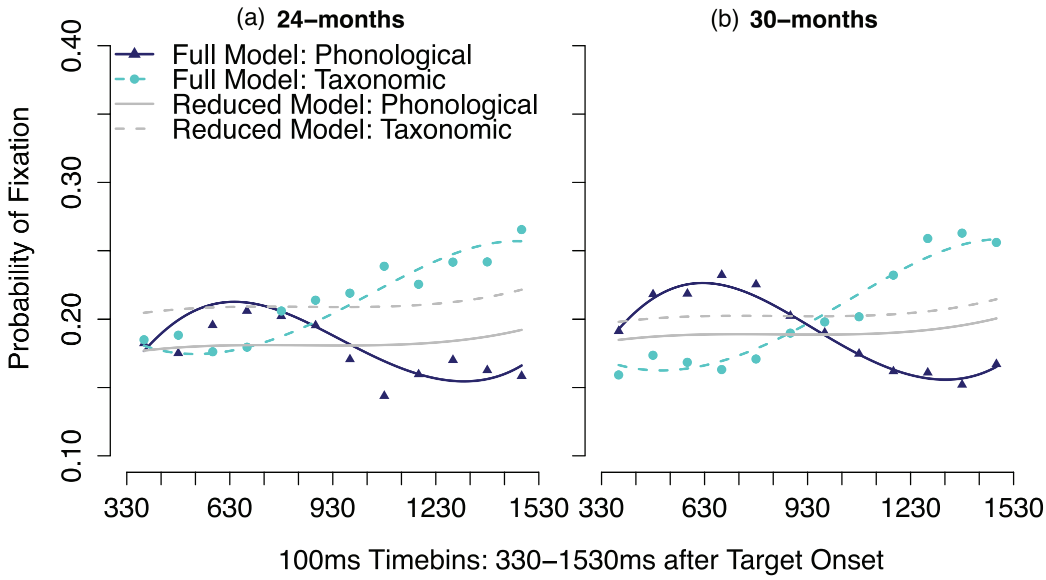

Figure 4.4. Experiment 2: Different time course of fixation for the phonological and taxonomic distractors in (a) 24-month-old and (b) 30-month-old participants. Data shown as points, the full model shown as coloured lines, the reduced model shown as grey lines. When the significant linear, quadratic and cubic terms for picture role is removed, the reduced model would predict no differences between the time course of phonological and taxonomic fixations.

4.3.2 Vocabulary Analysis

For the twenty-four 24-month-olds included in the analysis, the averaged OCDI receptive vocabulary score was 439 out of 553 words ($SD = 46$), and the averaged OCDI expressive vocabulary score was 276 out of 553 ($SD = 130$). For the twenty-four 30-month-olds included in the analysis, the averaged CDI receptive vocabulary score was 491 out of 553 ($SD = 33$), and the averaged OCDI expressive vocabulary score was 457 out of 553 ($SD = 70$). Twenty-four-month-olds had significantly lower OCDI receptive ($U = 112.5, p < .001$) and expressive vocabulary scores ($U = 93, p < .001$) than 30-month-olds. We examined whether these measures of vocabulary size were predictive of phonological and taxonomic fixation times. As shown in in Figure 4.5, there was a moderate positive correlation between receptive vocabulary score and average phonological distractor fixation time during 330-1530ms ($N = 48, r = .36, p = .0127$). There was no significant correlation between expressive vocabulary score and average phonological distractor fixation time ($N = 48, r = .14, p = .345$). There was no significant correlation between expressive vocabulary score and average taxonomic distractor fixation time ($N = 48, r = .12, p = .438$) or receptive vocabulary score ($N = 48, r = .26, p = .074$).

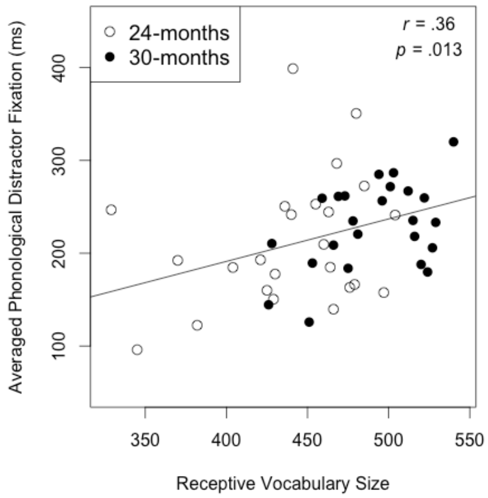

Figure 4.5. Experiment 2. Scatterplot showing a moderate positive correlation between vocabulary comprehension score and fixation time towards the phonological distractor during the period 330–1530ms after target word onset.

To further investigate the effects of participant vocabulary size, we computed a second mixed effects growth curve model. As receptive vocabulary size was significantly correlated with the amount of phonological fixation, we replaced age group with median-centred receptive vocabulary size as a continuous predictor in the model: we subtracted the median receptive OCDI score (469 words) of all 48 participants from each participants OCDI receptive score [1]. The data was modelled using third-order orthogonal polynomials with fixed effects of picture role (phonological vs. taxonomic vs. unrelated) on all time terms, receptive vocabulary size on the intercept and linear time terms, and picture co-occurrence in each timebin nested under participant as

[1]For ease of presentation, we divided the median-centred score by 100 to reduce the number of decimal places of the models estimated values, e.g., 0.0005457 to 0.05457. This does not change the t and p values of the predictions.

(a) (b)

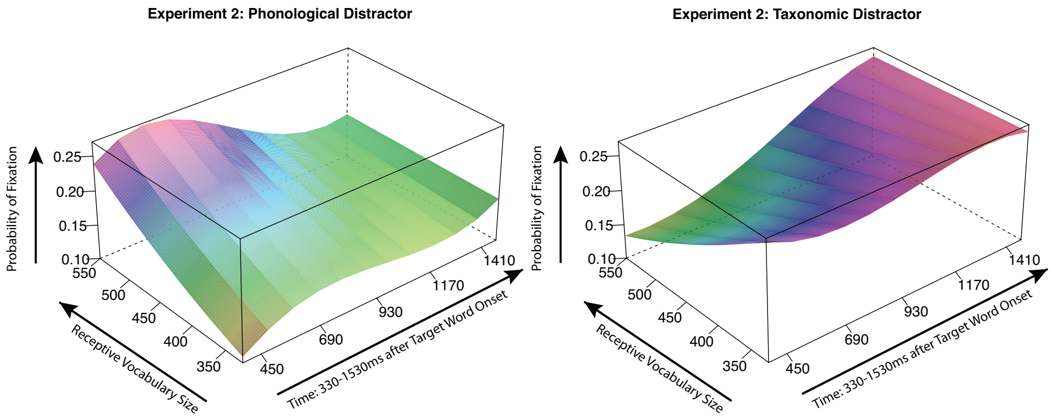

Figure 4.6. Experiment 2: Growth curve analysis with receptive vocabulary size as continuous predictor. (a) Phonological distractor fixation: Participants with a larger receptive vocabulary spent more time fixating the phonological distractor than participants with a smaller receptive vocabulary. (b) Taxonomic distractor fixation: Participants with a larger receptive vocabulary spent less time fixating the taxonomic distractor than participants with a smaller receptive vocabulary. The larger vocabulary participants devoted more attention to the phonological distractor early in the trial. Consequently, they began to attend the taxonomic distractor later in the trial.

random effects on the intercept and linear terms. The unrelated distractor and participants with a smaller vocabulary were treated as the baseline in the model, and relative parameters were estimated for the phonological and taxonomic distractors, and participants with a larger vocabulary. As seen in Figure 4.6a, participants with a larger receptive vocabulary had a substantially greater preference for the phonological distractor than participants with a smaller receptive vocabulary. In contrast, as seen in Figure 4.6b. participants with a smaller receptive vocabulary began to fixate the taxonomic distractor earlier.

Table 4.2 summarises the results for the fitted model. As in the previous model, there were significant effects of picture role. Regardless of receptive vocabulary size, participants fixated the phonological and taxonomic distractors more than the unrelated distractors. More importantly, there was a significant interaction between phonological fixations and vocabulary size. The significant intercept term indicates that participants with a larger receptive vocabulary size overall spent more time fixating the phonological distractor than those with a smaller receptive vocabulary. Moreover, the significant linear term indicates that the negative slope of phonological fixation was substantially steeper for participants with a larger receptive vocabulary than those with a smaller receptive vocabulary. There was also a significant interaction between taxonomic fixation and vocabulary size. The significant intercept term indicates that participants with a larger receptive vocabulary overall spent less time fixating the taxonomic distractor than those with a smaller receptive vocabulary.

Table 4.2. Experiment 2: Growth Curve Analysis by Receptive Vocabulary Size. The unrelated distractor and participants with smaller vocabulary were treated as baseline in the model, relative parameters were estimated for the phonological and taxonomic distractors, and participants with larger vocabulary.

Fixed Effects	**Model Terms**	**Est. (SE)**	**t**	**p**
Phonological	Intercept	0.12 (0.03)	4.45	<.001***
	Linear	-0.31 (0.09)	-3.27	.0011**
	Quadratic	-0.25 (0.09)	-2.71	.0069**
	Cubic	0.33 (0.09)	3.56	<.001***
Taxonomic	Intercept	0.26 (0.03)	9.60	<.001***
	Linear	0.78 (0.09)	8.43	<.001***
	Quadratic	-0.03 (0.09)	-0.30	.7617
	Cubic	-0.08 (0.09)	-0.83	.4041
Larger Vocabulary (receptive)	Intercept	0.05 (0.06)	0.93	.3551
	Linear	0.17 (0.16)	1.05	.2927
Phonological*Larger Vocabulary	Intercept	0.16 (0.07)	2.50	.0126*
	Linear	-0.61 (0.23)	-2.68	.0074**
Taxonomic*Larger Vocabulary	Intercept	-0.25 (0.06)	-3.93	.001***
	Linear	0.23 (0.22)	1.08	.2784
		$***p<.001, **p<.01, *p<.05$		

4.4 Discussion

The primary difference between this experiment and Experiment 1 was the exclusion of the target from the picture array in test trials. In Experiment 1, toddlers devoted most of their looking time at the target picture. The motivation for excluding the target in the current experiment was to examine the potency of the phonological and taxonomic distractors in attracting the child's attention upon hearing the target word, and thereby gaining insights into the nature of the phonological and taxonomic representations that are activated when toddlers hear a word. A similar strategy was adopted by Huettig & McQueen (2007) in their investigation of adults.

Using this *target-absent* scenario, we successfully demonstrated that there is generalised phonological and taxonomic activation during lexical access. Both 24- and 30-month-olds preferentially fixated the phonological distractor immediately after target word onset, reflecting early detection of a phonological match between the target word and the label associated with the phonological distractor picture. Phonological fixations can result from the target word activating phonologically-related words, leading to fixation of the phonologically-related referent, e.g., ‘penguin’ activates ‘pear’ leading to fixation of a pear. Alternatively, the phonological distractor may be implicitly named, perhaps during the preview period, permitting a partial match with the target word, e.g., the initial segment in ‘penguin’ matches the initial segment in the implicitly-named ‘pear’, resulting in fixation of the phonologically-related referent.

Our young participants also preferentially fixated the taxonomic distractor, though somewhat later in the time course of the trial, reflecting a match between the taxonomic category associated with the target word and the taxonomic distractor, e.g., ‘penguin’ activates the taxonomic category *animal* leading to fixation of the picture of a tiger. It is also possible that the match occurs at the lexical level, rather than the conceptual level. If the taxonomic distractor is implicitly named, eye-fixations can be guided by lexical-semantic matches, e.g., if the tiger is implicitly named, fixations may be driven by the lexical-semantic links between ‘penguin’ and ‘tiger’. It is noteworthy that our young participants demonstrated the same early preference for the phonological distractor over the taxonomic distractor as the adults in Huettig and McQueen's (2007) study. This finding indicates that toddlers, like adults, extract phonological information from the spoken word faster than they extract semantic information.

4.4.1 Vocabulary Size

We found that receptive vocabulary size, as opposed to age, was a better predictor of individual differences in this experiment. Participants with a larger receptive vocabulary displayed a stronger and longer phonological preference than participants with a smaller receptive vocabulary (see the interaction on the intercept and linear terms in Table 4.2). The larger vocabulary participants devoted more attention to the phonological distractors early in the trial. Consequently, they began to attend the taxonomic distractor later in the trial (see the interaction on the intercept term in Table 4.2). That age-related vocabulary growth is related to efficiency in spoken-word recognition efficiency is now well-attested. For example, faster response speeds and greater target-looking time during IPL spoken-word-recognition tasks as vocabulary size increases have been reported during and beyond the second year (Fernald et al., 2006, 2001; Zangl et al., 2005). Moreover, studies investigating novel word learning report that 14-month-olds' novel word learning performance is correlated with receptive and expressive vocabulary size (Werker et al., 2002).

In the current study, infants with a larger vocabulary were likely to have known the test words for longer, and had more experience hearing and saying these words, which in turn may strengthen the phonological representations and word connections in the mental lexicon. Consolidation of the phonological representation of words may in turn lead to easier and more rapid retrieval of names in response to viewing a picture, or retrieving other lexical candidates when hearing the auditory label, and hence faster and stronger responses to the phonological distractor. Larger vocabularies may also lead to a more *refined* phonological representation of words as denser lexicons require more detail to discriminate between similar words (cf. Metsala's (1998) Lexical Restructuring Model). Detailed phonological representation of words can in turn lead to enhanced early activation of alternative lexical candidates and hence a stronger pull towards phonological competitors[2].

To conclude, Experiment 2 demonstrated that the retrieval and matching of phonological representations precedes that of taxonomic representations. Moreover, infant's receptive vocabulary predicted the amount of phonological activation.

[2]Of course, another consequence of detailed phonological representations would be faster rejection of lexical competitors once the sufficient auditory information has been processed.

Chapter 5

Experiment 3: Phonological vs. Thematic

5.1 Introduction

In Experiment 2, we used a target-absent design to investigate the nature of the mental representations that are activated when toddlers hear a word that they understand. The results demonstrate that phonological and taxonomic information is extracted from the word in such a manner that it activates related words and concepts for toddlers as young as 24-months of age. The taxonomic distractor in Experiment 2 was defined as being visually dissimilar to a typical exemplar of the named target and lacking any associative relation to the named target, but belonging to the same taxonomic category (e.g., penguin and tiger are both *animals*). However, semantic relations need not be purely taxonomic but may also be based on thematic, associative or functional relations[1]. In Experiment 3, we ask whether another type of semantic information, *thematic/associative*, is extracted during word recognition such that a thematic distractor can attract fixations in the same manner as the taxonomic distractor in the previous experiment. The design of Experiment 3 is largely similar to that of Experiment 2, except that we replaced the taxonomic distractor with a thematic distractor. The thematic distractor was defined as an object or concrete context associated to the target (e.g., hair and brush) according to the University of South Florida word association norms (D. L. Nelson et al., 1998) and that the authors deemed as thematically-related. Thematically-related objects are not necessarily associated (e.g., spoon and dessert). However, since thematic relations are largely based on personal experiences and may vary greatly among individuals, word association is a useful indicator of the typicality of the thematic relations. Importantly, the objects chosen as thematically-related distractors are taxonomically-unrelated according to adult standards. The stimuli chosen according to these criteria are listed in the Appendix C.

We predicted that infants would preferentially fixate the phonological distractor early in the time course of a trial. As previous studies have established that toddlers by the age of two possess and utilise knowledge of thematic relations (e.g., Scott et al., 1982), we predicted that infants in Experiment 3 would preferentially fixate the thematic distractor over the unrelated distractor. Moreover, based on Huettig & McQueen (2007), we expected to observe

[1]We do not imply this to be an exhaustive listing of the range of semantic relations possible.

a late thematic preference. As Experiment 2 showed that vocabulary size was a better predictor than age in predicting the dynamics of phonological and semantic activation, we relaxed the age criterion to between 25- to 30-months in an attempt to cover a larger range of participant vocabulary size. Finally, a comparison of Experiments 2 and 3 would enable us to examine the relative time course and strengths of taxonomic and thematic activation in response to a comprehended word.

5.2 Method

5.2.1 Participants

Twenty-four participants between 25- and 30-month-old (M_{age} = 26.88, age range = 25.44–30.48, Male = 12, Female = 12) were recruited from British English monolingual households. Three participants were excluded due to fidgeting during testing. One participant was excluded as a result of not knowing most of the words used in this experiment, leaving only one trial available for analysis.

5.2.2 Design

The design of Experiment 3 was identical to Experiment 2, except that the post-naming phase lasted for 3000ms instead of 4000ms. Note that all the effects reported in the previous experiments took place within 2 seconds after word onset. See Tables C2 to C5 in Appendix C for the stimuli lists.

5.2.3 Stimuli

Among the 24 pictures and 24 target words (ranging from one to four syllables), 39 were based on items from the OCDI (Hamilton et al., 2000), while nine of them were extra word norm data that we collected alongside the OCDI since 2012. Target pictures and words in the test trials were chosen based on the criterion that at least 60% of 24-month-olds were reported to understand the word. Each trial included a phonological distractor, which shared the same onset consonant as the target word; a thematic distractor, which belonged to the same thematic category, and associated to the target according to the Edinburgh Associative Thesaurus (Kiss et al., 1972), and University of South Florida Free Association Norms (D. L. Nelson et al., 1998); and two unrelated distractors which were unrelated to each other, and to the target, phonological distractor and thematic distractor. Pictures in each set (e.g., house, brush, flower, and camera) were visually dissimilar. The phonological and unrelated distractors were unassociated to the target. See Table C1 in Appendix C for the stimuli yoke list.

Auditory Stimuli

The auditory stimuli were produced in the same way as in Experiment 2. In each trial, participants heard a sentence that included a prompt phrase followed by a target word, e.g., "Look at the bath!". Mean duration of target words was $797ms$.

Procedure

The procedure was identical to Experiments 1 and 2.

5.3 Results

There were in total 407 out of 576 trials available for analysis (on average 17 out of 24 trials per participant). A total of 104 trials (18%) were excluded due to unfamiliarity with the pictures or words used as reported by parents. A further 65 trials (11%) did not record any data due to infant fidgeting, or were excluded due to zero looking time or bias for one picture throughout the entire trial. The same pattern of results were obtained irrespective of the inclusion of words unknown to the infant. However, only results for the words known to the infant are included as these give the clearest findings. Figure 5.1 shows the grand mean of fixation probabilities for each type of distractor and indicates that participants fixated the phonological distractor more than the unrelated distractors earlier in the time course, and fixated the thematic distractor more than the unrelated distractors later in the time course.

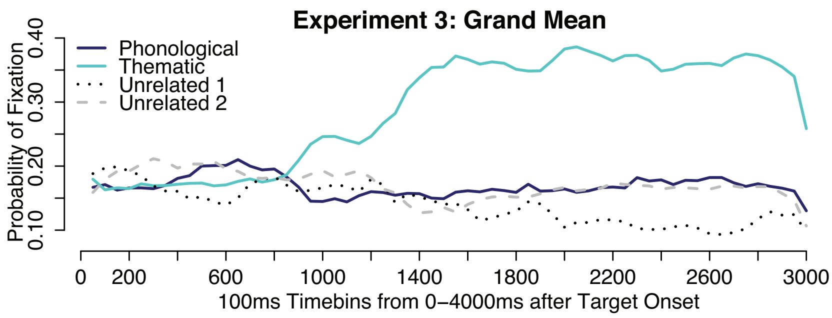

Figure 5.1. Experiment 3. Time course of fixation from onset of the auditory label of the target.

5.3.1 Vocabulary Analysis

Experiment 2 demonstrated a relationship between vocabulary size and phonological fixations. We therefore examine possible relationships between vocabulary size and fixations of the different types of distractor before proceeding to the analysis of fixation growth curves. The averaged OCDI receptive score was 436 out 553 ($SD = 57$), and the averaged OCDI expressive score was 305 out of 553 ($SD = 120$). One participant was excluded in the vocabulary analysis because the parent did not complete the full OCDI, but only the experimental stimuli checklist during the visit. Phonological distractor fixation time during the 330–1530ms timebin was not correlated with receptive or expressive vocabulary size (Receptive: $N = 23, r = -.066, p = .765$; Expressive: $N = 23, r = -.012, p = .958$). Thematic distractor fixation time was not correlated with receptive vocabulary size ($N = 23, r = -.07, p = .753$). However, as shown in Figure 5.2 there was a significant correlation between thematic fixation and expressive score ($N = 23, r = .414, p = .049$).

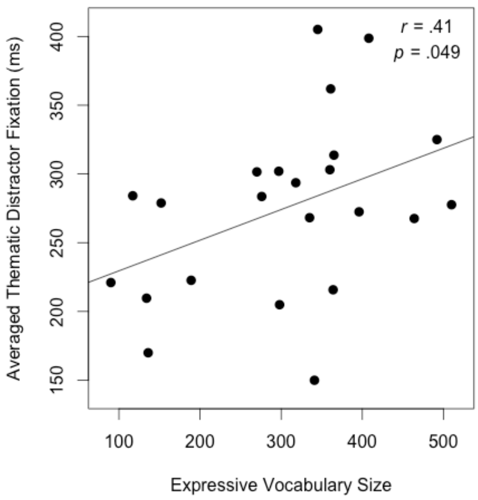

Figure 5.2. Experiment 3. Scatterplot showing a moderate positive correlation between expressive vocabulary score and fixation time towards the thematic distractor during the period 330-1530ms after target word onset.

5.3.2 Growth Curve Analysis

As expressive vocabulary size was correlated with thematic fixation times, we included the median-centred expressive vocabulary size as a continuous predictor in the model. As in Experiment 2, we subtracted the median expressive OCDI score (335 words). To facilitate comparison with earlier experiments, we analysed the data using the same time window: 330–1530ms after target onset. As in Experiment 2, participants showed no systematic preference for Unrelated Distractor 1 over Unrelated Distractor 2 during the 330–1530ms time window ($M_{difference} = .03, t(23) = -1.346, p = .191$). Therefore, the average of fixations for both unrelated distractors was used as the baseline in the analysis. The overall time course of fixations was captured by third-order orthogonal polynomials with fixed effects of picture role (phonological vs. thematic vs. unrelated) on all time terms, expressive vocabulary size

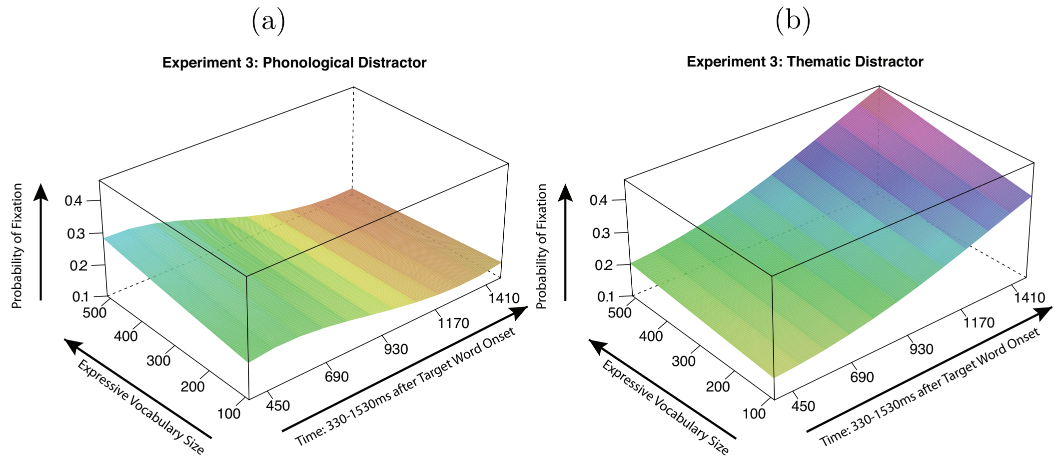

Figure 5.3. Experiment 3: Growth curve analysis with expressive vocabulary size as continuous predictor. (a) Phonological distractor fixation: Participants with a larger expressive vocabulary had a greater preference for the phonological distractor than those with a smaller expressive vocabulary. (b) Thematic distractor fixation: Participants with a larger expressive vocabulary showed an earlier and greater preference for the thematic distractor than those with a smaller expressive vocabulary.

on the intercept and linear terms, and picture co-occurrence in each timebin nested under participant as random effects on the intercept and linear terms. The unrelated distractor and participants with a smaller vocabulary were treated as the baseline in the model, and relative parameters were estimated for the phonological and taxonomic distractors, and the participants with a larger expressive vocabulary size.

Figure 5.3 shows the model estimation. As seen in Figure 5.3a, participants with a larger expressive vocabulary had a greater preference for the phonological distractor than those with a smaller expressive vocabulary. In contrast, Figure 5.3b shows that participants with a larger expressive vocabulary showed an earlier and greater preference for the thematic distractor than those with a smaller expressive vocabulary.

Table 5.1 summarises the results of the statistical model. The significant phonological intercept term indicates that participants fixated the phonological distractor more than the unrelated distractor. There was a significant interaction between amount of looking at the phonological distractor and expressive vocabulary size (Phonological*Larger Vocabulary), indicating that participants with a larger expressive vocabulary overall spent more time fixating the phonological distractor than those with a smaller expressive vocabulary. Similarly, the significant thematic intercept term indicates that participants spent more time fixating the thematic distractor than the unrelated distractor. The significant linear term confirms that fixations towards the thematic and unrelated distractors followed different trends with fixations towards the thematic distractor increasing throughout the time window. Moreover, there was a significant interaction between amount of looking at the thematic distractor and expressive vocabulary size (Thematic*Larger Vocabulary). Overall, participants with a larger expressive vocabulary fixated the thematic distractor more than participants with a smaller expressive vocabulary.

To compare the time course of phonological and thematic fixations, we relevelled the same model using the phonological distractor as the baseline measurement. The significant intercept term indicates that, overall, participants fixated the thematic distractor more than the phonological distractor ($Estimates = 0.33(0.04), t = 7.35, p<.001$). More importantly, as in Experiment 2, phonological fixation peaked earlier than thematic fixation. The significant linear term ($Estimates = 1.69(0.15), t = 11.02, p<.001$) and cu-

Table 5.1. Experiment 3: Growth Curve Analysis by Expressive Vocabulary Size. The unrelated distractor and participants with smaller vocabulary were treated as baseline in the model, relative parameters were estimated for the phonological distractor, thematic distractor, and participants with larger vocabulary.

Fixed Effects	**Model Terms**	**Est. (SE)**	**t**	**p**
Phonological	Intercept	0.14 (0.05)	2.99	.003**
	Linear	-0.18 (0.16)	-1.07	.2857
	Quadratic	0.19 (0.16)	1.18	.2394
	Cubic	0.26 (0.16)	1.62	.1056
Thematic	Intercept	0.47 (0.05)	10.25	<.001***
	Linear	1.51 (0.16)	9.50	<.001***
	Quadratic	0.28 (0.16)	1.80	.0725
	Cubic	-0.04 (0.15)	-0.24	.8083
Larger Vocabulary (expressive)	Intercept	-0.06 (0.04)	-1.59	.1272
	Linear	-0.10 (0.10)	-0.98	.3285
Phonological*Larger Vocabulary	Intercept	0.08 (0.04)	2.04	.0423*
	Linear	-0.07 (0.13)	-0.53	.5985
Thematic*Larger Vocabulary	Intercept	0.14 (0.04)	3.79	<.001***
	Linear	0.14 (0.13)	1.08	.2806
		$***p<.001, **p<.01, *p<.05$		

bic term ($Estimates = -0.3(0.15), t = -1.98, p = .0481$) confirm that the growth trend of thematic fixation was significantly different from that of phonological fixation.

5.4 Discussion

The toddlers in this experiment preferentially fixated the phonological distractor immediately after target word onset, reflecting early detection of a phonological match between the target word and the label associated with the phonological distractor picture, and replicating a similar effect reported in Experiment 2. As predicted, they also preferentially fixated the thematic distractor later in the trial, reflecting a match between thematic information associated with the target word and the thematic distractor, e.g., 'bath' activates the thematic information leading to fixation of the picture of soap. The 'pull' of the thematic distractor later in the trial resembles that of the taxonomic distractor in Experiment 2 suggesting that thematic/associative information is accessed later than phonological information when comprehending a word.

Experiment 3 also replicates the finding in Experiment 2 that early fixations of the phonological distractor were more pronounced for the larger vocabulary infants (though note in this case that expressive vocabulary was the continuous variable entered into the model). The finding that higher expressive vocabulary users also show stronger preferences for the thematic distractor might be related to the emergence of combinatorial language. Productive word combinations permit the toddler to highlight the relationship between the items referenced in an utterance and so strengthen any associations between them. Increasing expressive vocabulary size in toddlers commonly goes hand-in-hand with the emergence of combinatorial utterances (Bates et al., 1988). The positive relationship between expressive vocabulary size and amount of thematic fixation for the toddlers in this study might be an indirect result of their level of command of combinatorial language. In the absence of any direct evidence of these toddlers' combinatorial language, such explanations must, however, remain speculative. Note, however, that one might predict that there should be no such relation between level of taxonomic fixations and expressive vocabulary size in Experiment 2 since taxonomically-related objects are less likely to co-occur together in an utterance than thematically-related items. When expressive vocabulary size is entered as a predictor in the growth curve analysis for Experiment 2, no systematic positive relationship between taxonomic fixations and expressive vocabulary size is found ($t = -1.68, p = .0937$)—indeed, the negative t-value points in the opposite direction.

5.4.1 Experiment 2 vs. Experiment 3

Experiments 2 and 3 differ primarily in the status of the semantic distractor: taxonomic in the former and thematic/associative in the latter. Since the design of the experiments was otherwise identical, it is meaningful to ask whether the two types of semantic foils influenced eye-fixations in similar ways. It is apparent that both attracted the toddlers' attention approximately within $1000ms$ after target word onset, even though neither matched the target. We can also use growth curve analysis to ask whether taxonomic and thematic foils are otherwise equivalent. We compared the findings of all participants in Experiments 2 and 3 with a mixed effects growth curve model using third-order orthogonal polynomials with fixed effects of picture role (phonological vs. semantic) on all time terms, experiment (Experiment 2 (taxonomic) vs. Experiment 3 (thematic)) on intercept and slope terms, and picture co-occurrence nested under participant as random effects on the intercept and linear terms. The modelled growth curves are depicted separately in Figure 5.4 for phonological distractors (left panel) and semantic distractors (right panel), each against their respective unrelated baseline distractors.

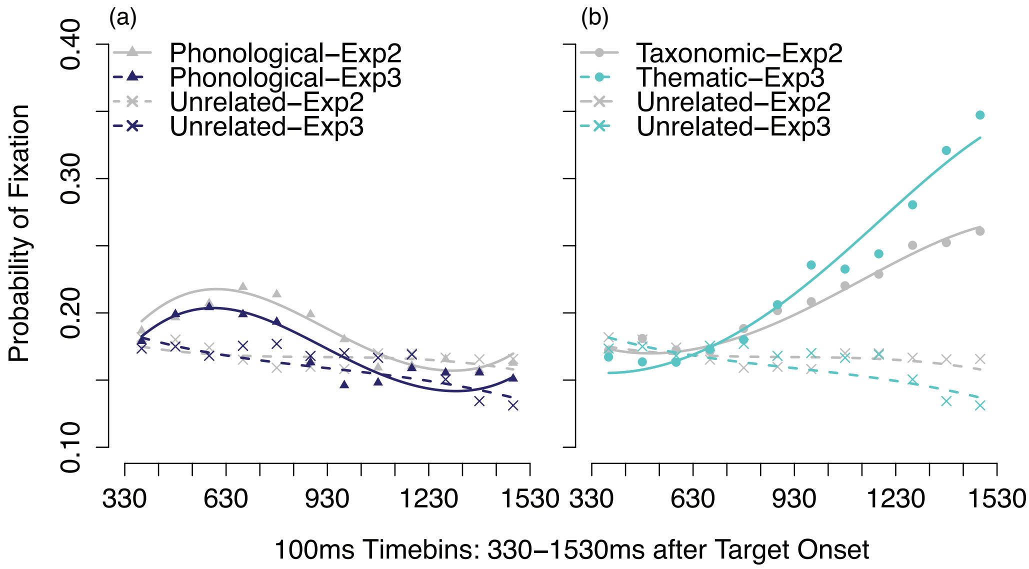

Figure 5.4. Experiment 2 vs. Experiment 3: Growth curve analysis of all participants in 2 and Experiment 3. Data shown in points, the model shown in lines for (a) Phonological distractors fixation against unrelated distractors fixation. (b) Taxonomic or thematic distractors fixation against unrelated distractors fixation.

As seen in Figure 5.4, the fitted data suggest that participants' preference for the phonological distractor (left panel) over the unrelated distractor followed a similar trend in both Experiments 2 and 3. In contrast, participants' preference for the thematic distractor in Experiment 3 increased at a faster rate and reached a higher peak than that for the taxonomic distractor in Experiment 2 (right panel).

Table 5.2 summarises the model's results. In both experiments, we observed an early phonological preference (significant intercept, linear and cubic terms) and a late semantic preference (significant intercept and linear terms).

Table 5.2. Experiment 2 vs. Experiment 3: Growth Curve Analysis. The unrelated distractor and Experiment 2 were treated as baseline in the model, relative parameters were estimated for the phonological distractor, semantic distractor and Experiment 3.

Fixed Effects	Model Terms	Est. (SE)	t	p
Phonological	Intercept	0.13 (0.03)	3.97	<.001***
	Linear	-0.33 (0.11)	-2.93	.0035**
	Quadratic	-0.05 (0.08)	-0.55	.5826
	Cubic	0.29 (0.08)	3.41	<.001***
Semantic (Taxonomic and Thematic)	Intercept	0.25 (0.03)	7.89	<.001***
	Linear	0.77 (0.11)	6.98	<.001***
	Quadratic	0.13 (0.08)	1.58	.1153
	Cubic	-0.06 (0.08)	-0.68	.4972
Experiment 3	Intercept	-0.06 (0.05)	-1.29	.2009
	Linear	-0.23 (0.13)	-1.85	.0644
Phonological*Experiment 3	Intercept	0.04 (0.05)	-0.83	.4040
	Linear	0.17(0.17)	1.02	.3085
Semantic*Experiment 3	Intercept	0.16 (0.05)	3.26	.0011**
	Linear	0.72 (0.16)	4.39	<.001***
		$***p<.001, **p<.01, *p<.05$		

The non-significant effect of Experiment indicates that, overall, participants spent similar amounts of time looking at the four pictures in both experiments. The non-significant interaction term 'Phonological*Experiment 3' confirms that participants showed similar levels of phonological preference in both experiments. However, the significant intercept term on the interaction 'Semantic*Experiment 3' indicates that there was an overall greater thematic preference than taxonomic preference. Moreover, the significant linear term on the interaction indicates, as is readily seen in Figure 5.4, that thematic fixations increased at a faster rate than taxonomic fixations.

To compare the amount of phonological and semantic fixations, we re-levelled the same model using the phonological distractor as the baseline measurement. A significant intercept term indicated that overall, participants fixated both the taxonomic and thematic distractors more than the phonological distractor (Estimate $= 0.12(0.03), t = 3.94, p<.001$).

To conclude, Experiment 3 demonstrated that the retrieval and matching of phonological representations precedes that of thematic representations. Moreover, infant's expressive vocabulary predicted the amount of phonological activation as well as thematic activation. A comparison between Experiment 2 and 3 suggest that thematic activation is stronger than taxonomic activation.

Chapter 6

Experiment 4: Cohort vs. Rhyme

6.1 Introduction

Experiment 4 investigates the time course and competition of the activation of two types of phonological representations: cohort[1] and rhyme. Do infants have a greater preference for one type of phonological representations over the other?

6.1.1 Cohort vs. Rhyme

The original cohort model (Marslen-Wilson, 1987) proposes that word recognition is incremental. The initial sounds of a word activate a set of candidate words in the lexicon that start with the same phonemes. As the word un-

[1]Similar to the phonological distractor in Experiments 1-3.

folds, candidate words that no longer match the speech input are eliminated until only one word is left. For example, upon hearing the first sound /d/ of the word 'dog', candidate words, such as dog, digger and dress, are activated. The cohort model is supported by the findings of cohort priming in lexical decision tasks. Participants' lexical decision response is facilitated if the prime and target words share the same onset consonant (Marslen-Wilson & Zwitserlood, 1989; Slowiaczek et al., 1987; Zwitserlood, 1989).

The TRACE model (McClelland & Elman, 1986) assumes that word recognition is not only incremental but also continuous, and therefore, words that match the sensory input in the middle or at the end of the signal, such as rhyme words, will also be activated (e.g., 'dog' will activate 'log'). However, findings of rhyme priming, compared to that of cohort priming, are less consistent. While some studies found that lexical decision is facilitated by rhyme prime words (Slowiaczek et al., 1987), some studies found no rhyme priming effects (Emmorey, 1989; Marslen-Wilson & Zwitserlood, 1989). Other studies observed rhyme priming only under specific conditions (Andruski et al., 1994; Connine et al., 1993; Marslen-Wilson et al., 1996). For example, Marslen-Wilson et al. (1996) observed rhyme priming only in a cross-modal but not an auditory-auditory paradigm. In addition, some studies have shown priming for embedded words, e.g., bone and trombone (Shillcock, 1990), morphologically-similar words, e.g., submit and permit, or words that share the same segment, e.g., tango and cargo (Emmorey, 1989)

Adult VWP studies have provided evidence for the matching of both cohort and rhyme representations during spoken-word recognition. In Allopenna et al. (1998)'s study, participants were shown an array of four pictures, including the target (e.g., beaker), a cohort distractor with the same onset and vowel as the target (e.g., beetle), a rhyme distractor (e.g., speaker) and an unrelated distractor (e.g., carriage). The authors found that adults demonstrated a stronger and earlier cohort activation, and a weaker and later rhyme activation. These findings demonstrate that spoken-word recognition is both incremental and continuous. While word onset is important for spoken-word recognition, the middle and the end of the word are also considered, which could be useful when the listener has missed the beginning of the word.

6.1.2 Development of Phonological Processing

Similar to adults, infants are sensitive to not only the beginning of words, but also the middle and end of words. For example, infants, as young as 7.5 months, are able to categorise on the basis of rhyme (Hayes et al., 2000). Moreover, rhyme words can lead to priming effects in infants by the age of two (Mani et al., 2012). For example, Mani et al. (2012) in a phono-semantic priming study demonstrated that 'boat' primes 'coat', which in turn primes 'hat'.

There are two views regarding how young children process rhyme words. The first view proposes an analytic approach of rhyme word processing. The onset-rime theory (Treiman et al., 1995) argues that as English words are naturally separated by syllables into two parts: onset (first onset consonant) and rime (vowel and final consonant), and that the judgement of rhyme words involves the comparison of the rime constituents of words. Some studies have demonstrated that young children are aware of onsets and rimes. For example, 2-year-olds would substitute rime segements of words (Wijnen, 1992), and that children's onset-rime awareness at four years old predicts reading ability at six years old (Bryant et al., 1990).

The second view argues that rhyme words are recognised based on global similarities (e.g., Charles-Luce & Luce, 1990; Jusczyk, 1993; Metsala & Walley, 1998; Walley, 1993). This view assumes that, initially, infants form holistic lexical representations of words based on large chunks or the overall acoustics. It is only when lexical entries increase in number and require differentiation that word representations undergo finer segmentation (i.e., whole to part representation). Evidence supporting this view comes from studies that use the rhyme judgement task. In Cardoso-Martins's(1994) study, children were asked to judge which one of two words rhyme with a prime word, e.g.,"Does 'fish' or 'pen' end up like 'dish'?". The author found that children's performance was poorer when the distractor (i.e., the non-rhyme word) was phonologically related to the prime word (e.g.,"Does 'mop' or 'tap' end up like 'top'?"), compared to a distractor that is semantically related to the prime word (e.g.,"Does 'hat' or 'dog' end up like 'cat'?"). The interference effect has also been demonstrated in three- and four-year-olds using a picture naming version of the rhyme judgement task (J. M. Carroll & Snowling, 2001). Furthermore, a developmental effect has been observed. Compared to younger children (five- and six-year-olds) without reading experience, older children (seven-year-olds) with reading experience were less likely to be affected by the phonologically-related distractor. These findings suggest that compared to younger children, older children have more sophisticated ways of processing and comparing phonological information.

6.1.3 The Current Study

The existing literature indicates that infants and children are sensitive to both cohort and rhyme information of words. In this experiment, I will investigate the time course in which cohort and rhyme representations are retrieved and matched during spoken-word recognition in 24- and 30-month-olds. Figure 6.1 illustrates the timeline of a trial. Participants heard a sentence with a target word (e.g., “Look at the boat”), and saw a cohort distractor (e.g., bowl), a rhyme distractor (e.g., coat), and two unrelated distractors (e.g., door and tree). Based on previous adult visual world findings (Allopenna et al., 1998) and infant cohort and rhyme priming findings (Mani et al., 2012; Mani & Plunkett, 2011), it was predicted that infants would fixate the cohort distractor more than the unrelated distractors. Similarly, it was predicted that participants would fixate the rhyme distractors more than the unrelated distractors. As speech is incremental, it was predicted that participants would demonstrate an early preference for the cohort distractor and a late preference for the rhyme distractor. As Experiment 2 and

3 demonstrated that participants with a larger vocabulary demonstrated a larger phonological activation, it is predicted that participants with a larger vocabulary (typically 30-month-olds) will show stronger cohort and rhyme preference than those with a smaller vocabulary (typically 24-month-olds).

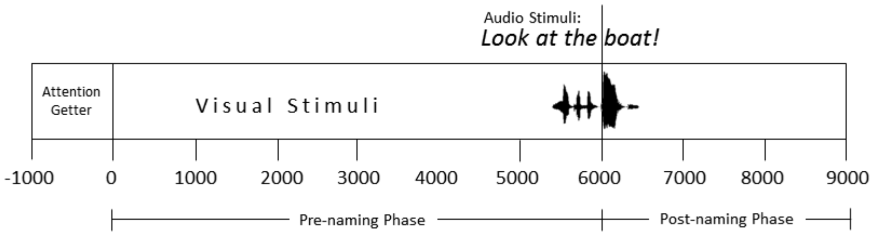

Figure 6.1. Experiment 4. Trial timeline. Each trial began with a 1000ms attention getter. The four picture array, a cohort distractor (e.g., bowl), a rhyme distractor (e.g., coat) and two unrelated distrators (e.g., door and tree), appeared for a total of 9000ms. Onset of the auditory label of the target word (e.g., boat) was always at 6000ms.

6.2 Method

6.2.1 Participants

Twenty-four 24-month-olds (M_{age} = 24.22, age range = 23.74–25.12, Male = 8, Female = 16) and twenty-four 30-month-olds (M_{age} = 30.1, age range = 29.16–34.06, Male = 11, Female = 13) recruited from a British English monolingual household were included in the analysis. For both age groups, four participants were excluded due to fidgeting during testing or bad calibration. Seven participants were excluded as a result of not knowing most of the words used in this experiment, leaving less than three trials available for analysis.

6.2.2 Design

The design of this experiment is based on that of Allopenna et al. (1998), but without the target picture. Each participant saw a total of eight target-absent test trials. Each trial included a cohort distractor (shares the same first consonant and vowel with the target word); a rhyme distractor (rhymes with the target word); and two unrelated distractors (unrelated to the target, cohort and rhyme distractors). As shown in Figure 6.1, there was an attention getter at the beginning of each trial. The four pictures appeared on the screen for a total of $9000ms$. The target word onset, e.g., Boat, was always at $6000ms$, and was preceded by a prompt phrase "Look at the". Target word onset thus divided the trial into two phases, a $6000ms$ pre-naming phase[2] and $3000ms$ post-naming phase. The post-naming phase was three seconds. There were 6 target-present filler trials, which served to maintain the participants' attention, as infants at this age can easily get frustrated if the target word never matches any of the pictures. Participants were randomly assigned to one of four lists (see Tables D2 to D5 in Appendix D). There was always a filler trial before the first test trial and between every two test trials.

[2]To ensure that infants have had time to identify all the pictures and the potential phonological properties e.g., through implicit naming, this experiment has a longer pre-naming phase than the previous experiments (i.e., six seconds).

6.2.3 Stimuli

Among the 40 pictures and target words (ranging from one to four syllables), 35 were chosen from the Oxford Communicative Development Inventory (CDI) (Hamilton et al., 2000), while five of them are extra words that we have been collecting data alongside the Oxford CDI since 2012. Target words and pictures in the test trials were chosen based on the criterion that at least 60% of 24-month-olds were reported to understand the word. The stimuli were not yoked because the infant vocabulary is limited, and I was not able to form enough quadruples of words in which each word could act as both a cohort and rhyme distractor.

Auditory Stimuli

The auditory stimuli were produced in the same way as in Experiment 2. In each trial, participants heard a sentence that included a prompt phrase followed by a target word, e.g., "Look at the bath!". Mean duration of target words was 606ms.

6.2.4 Counterbalancing

Picture location is counterbalanced between participants. Between participants, each picture appeared at all four locations for an equal number of times. Location of the picture roles (i.e., the cohort distractor, rhyme distractor, unrelated distractor 1 and unrelated distractor 2) was counterbalanced both within and between participants. Within participant, each picture role appeared twice at each of the four screen locations. Between participants, picture roles in each trial were counterbalanced to appear at all four locations on the screen for an equal number of times. Trials were sequenced in a way so that there were no rhyming words or pictures presented in any two consecutive trials. Moreover, target words in any two consecutive trials were not semantically related.

Procedure

The procedure was identical to Experiments 1–3.

6.3 Results

Overall, 24-month-olds contributed 153 out of 192 trials (on average 6 out of 8 trials per participant) for analysis. There were 34 trials (17%) excluded because of unfamiliarity with pictures or words used, and 5 trials (3%) excluded due to zero post-naming looking time. Thirty-month-olds contributed 184 out of 192 trials (on average 8 out of 8 trials per participant) for analysis. There were 10 trials (5%) excluded because of unfamiliarity with pictures or words used. Figure 6.2 shows the time course of fixation of 24-month-olds (top panel), 30-month-olds (middle panel) and the grand mean (bottom panel). The grand mean plot suggests that 600-3000ms after target word onset would capture participants' preference for the cohort and rhyme distractors.

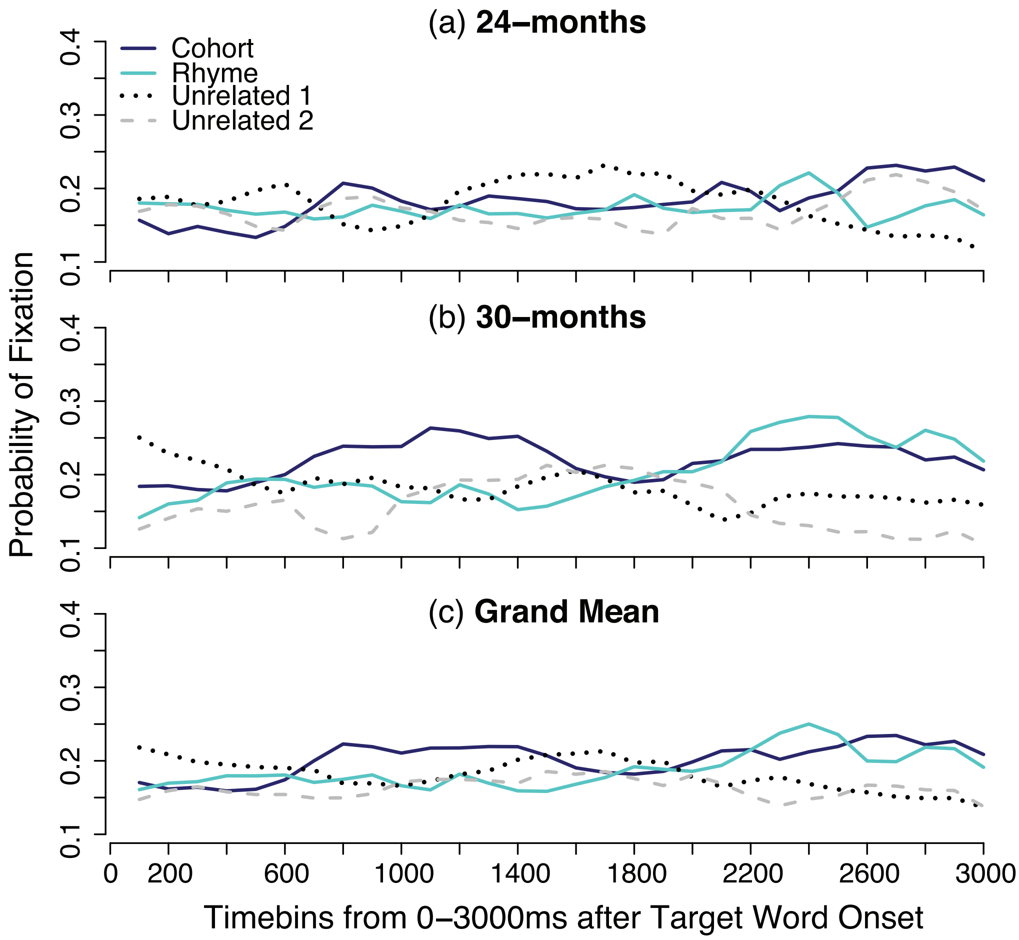

Figure 6.2. Experiment 4: Time course of fixation from onset of the auditory label of the target in (a) 24-month-olds, (b) 30-month-olds, and (c) grand mean of both age groups.

6.3.1 Growth Curve Analysis

A paired-sample t-test indicate that 24-month-old participants showed no systematic preference for Distractor 1 and Distractor 2 during the 600–3000ms time window ($M_{difference} = 0.01, t(23) = 0.21, p = .8355$). Similarly, 30-month-old participants showed no systematic preference for Distractor 1 and Distractor 2 ($M_{difference} = 0.01, t(23) = 0.2323, p = .8183$). Therefore, the average of fixations for both unrelated distractors was used as the base-line in the analysis. The overall time course of fixations was captured by third-order orthogonal polynomials with fixed effects of picture role (cohort vs. rhyme vs. unrelated) and age group (24-months vs.30-months) on all time terms, and picture co-occurrence in each timebin nested under participant as random effects on the intercept and linear terms. The unrelated distractor and 30-month-old participants were treated as the baseline in the model, and relative parameters were estimated for the cohort and rhyme distractors, and 24-month-old participants.

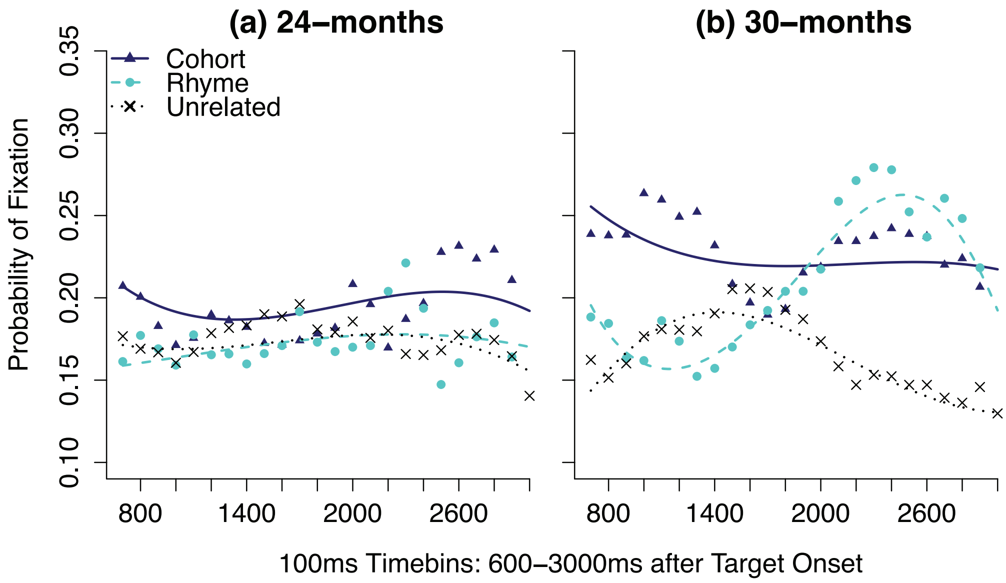

Figure 6.3. Experiment 4: Growth curve analysis of (a) 24-month-old and (b) 30-month-old participants. Data shown as points, the model shown as lines.

Figure 6.3 shows the data in points, and the growth curve model as lines. It suggests different patterns of fixation for the two age groups. For 24-month-olds, the data points suggest little to no preference for the cohort and rhyme distractors. In contrast, the data points suggest that 30-month-olds showed a preference for the cohort distractor earlier in the time course and the rhyme distractor towards the end of the time course.

Table 6.1 summarises the results of the statistical model. There was a significant effect of cohort fixation. The significant intercept term indicates that participants, regardless of age group, fixated the cohort distractor more than the unrelated distractor. The significant quadratic term confirms that the curves of cohort and unrelated distractor fixation followed different trends. Moreover, there was a significant interaction of cohort distractor and age group (Cohort*24-month-olds). The significant intercept term indicates that 24-month-old participants fixated the cohort distractor significantly less than 30-month-old participants.

There was also a significant effect of rhyme fixation. The significant intercept term indicates that participants, regardless of age group, fixated the rhyme distractor more than the unrelated distractor. The significant linear term indicates that the positive slope of rhyme distractor fixation was significantly steeper than that of unrelated distractor fixation. The significant cubic term confirms that, compared to the unrelated distractor, the curve of rhyme distractor peaked at the end of the time course. Moreover, there was a significant interaction of rhyme distractor and age group (Rhyme*24-month-olds). The significant intercept term indicates that 24-month-olds fixated the rhyme distractor significantly less than 30-month-olds. The significant linear and cubic terms indicate that the slope and curve of rhyme distractor fixation differed between the two age groups. Rhyme distractor fixation was almost flat for 24-month-olds. In contrast, rhyme distractor fixation followed a cubic trend and peaked at the end of the time course for 30-month-olds.

Table 6.1. Experiment 4: Growth Curve Analysis. The unrelated distractor and 30-month-old age group were treated as baseline in the model, relative parameters were estimated for the cohort distractor, rhyme distractor and 24-month-old age group.

Fixed Effects	**Model Terms**	**Est. (SE)**	t	p
Cohort	Intercept	0.40(0.04)	8.96	<.001***
	Linear	0.30(0.23)	1.31	.1892
	Quadratic	0.65(0.23)	2.81	.005**
	Cubic	-0.36(0.23)	-1.55	.1202
Rhyme	Intercept	0.28(0.05)	6.05	<.001***
	Linear	1.35(0.23)	5.77	<.001***
	Quadratic	0.35(0.24)	1.47	.1411
	Cubic	-0.98(0.24)	-4.1	<.001***
24-month-olds	Intercept	0.06(0.09)	0.67	.5033
	Linear	0.46(0.26)	1.77	.0763
	Quadratic	0.36(0.24)	1.48	.1387
	Cubic	-0.38(0.24)	-1.56	.1197
Cohort*24-month-olds	Intercept	-0.24(0.07)	-3.54	<.001***
	Linear	-0.19(0.34)	-0.56	.5737
	Quadratic	-0.45(0.35)	-1.29	.1988
	Cubic	0.30(0.35)	0.86	.3891
Rhyme*24-month-olds	Intercept	-0.28(0.07)	-3.98	<.001***
	Linear	-1.15(0.35)	-3.27	.0011**
	Quadratic	-0.33(0.36)	-0.91	.3613
	Cubic	1.06(0.36)	2.93	.0034**
		$***p<.001, **p<.01, *p<.05$		

To compare the amount of cohort and rhyme fixations, we re-levelled the same model using the rhyme distractor as the baseline measurement. A significant intercept term indicated that overall, participants fixated the cohort distractor more than the rhyme distractor (Estimate $= 0.13(0.04), t = 2.85, p = .0044$). Moreover, the significant linear (Estimate $= -1.04(0.23), t = -4.61, p<.001$) and cubic (Estimate $= 0.61(0.24), t = 2.58, p = .0101$) terms indicate that cohort and rhyme distractor fixation followed different trends and time courses. While cohort fixation began early in the time course and continued toward the end of the time course, rhyme distractor fixation began only from around $1800ms$ after target onset.

6.3.2 Vocabulary

For 24-month-olds, the averaged OCDI receptive score was 440 out of 553 words ($SD = 46$), and the averaged OCDI expressive score was 277 out of 553 words ($SD = 130$). For 30-month-olds, the averaged OCDI receptive score was 490 out of 553 words ($SD = 32$), and the averaged OCDI expressive score was 456 out of 553 words ($SD = 69$). The 24-month-olds had significantly smaller receptive ($U(17, 31) = 108.5, p < .001$) and expressive OCDI scores ($U(15, 34) = 50, p < .001$) than 30-month-olds.

There was no significant correlation between the average fixation time of the cohort distractor during 600–$3000ms$ after target word onset and either receptive score ($N = 48, r = .1605, p = .2756$) or expressive OCDI score ($N = 48, r = .0905, p = .5408$). Similarly, there were no significant correlations between averaged fixation time of the rhyme distractor during 600–$3000ms$ after target word onset and either receptive ($N = 48, r = .1558, p = .2903$) or expressive OCDI scores ($N = 48, r = .046, p = .7564$). In fact, the growth curve model worsened when either receptive or expressive OCDI score replaced age group as a predictor[3]. Specifically, the number of significant interaction terms (Cohort*Vocabulary or Rhyme*Vocabulary) reduced, as

[3]see models in Tables D6 and D7 in Appendix D

did the significant intercept terms, indicating no overall differences in cohort and rhyme distractor fixation between participants with a larger and smaller vocabulary.

6.4 Discussion

As predicted, overall, participants in this experiment preferentially demonstrated an early preference for the cohort distractor, from approximately 600–3000ms after target word onset. Participants also demonstrated a late preference for the rhyme distractor, from approximately 1800–3000ms. As speech is incremental, it is perhaps unsurprising that representations of the beginning of a word were activated and matched before representations of the middle and end of word. Moreover, participants showed an overall greater preference for the cohort distractor than the rhyme distractor. These findings are similar to the adult findings in Allopenna et al. (1998), confirming that incremental and continuous word recognition (McClelland & Elman, 1986) is an integral part of the word recognition process, which is already in place during the early years of life.

6.4.1 Age Group Differences

There was a significant interaction of picture role and age group (see interactions effects of Cohort*24-month-olds and Rhyme*24-month-olds in Table 6.1. As seen in Figure 6.3, the cohort and rhyme preferences were only observed in 30-month-olds, but not in 24-month-olds. This finding is surprising, as Experiment 2 demonstrated an early, albeit small, cohort preference[4] in 24-month-olds. Moreover, previous infant studies have demonstrated a priming effect with both cohort and rhyme prime words with 24-month-olds (Mani et al., 2012).

What could be the reason that 24-month-olds showed no preference for the cohort and rhyme distractors in this experiment? One possibility is that the 24-month-old participants in the current experiment have a small vocabulary size. In Experiments 2 and 3, participants with a low vocabulary score showed little to no phonological activation. The vocabulary analyses of the current experiment indicate that 24-month-olds' receptive and expressive OCDI scores were indeed significantly smaller than that of 30-month-olds'. However, there was no correlation between cohort and rhyme fixation time and OCDI scores. In fact, the growth curve model worsened when receptive or expressive vocabulary score replaced age group as a predictor.

Another possible explanation is that there is a developmental difference in phonological processing at 24- and 30-months. It has been proposed that phonological processing during early childhood is based on holistic processing and the degree of global similarities (e.g., Walley, 1993). In fact, young children's performance in the rhyme judgement task is impaired when they have to choose between a word that rhymes with the prime word, and a word that shares the onset and final consonants with the prime word (e.g., top: mop vs. tap) (Cardoso-Martins, 1994; J. M. Carroll & Snowling, 2001).

[4]It was known as the phonological distractor

The impaired performance could be thought of as mutual inhibition between competing candidate words. In connectionist models of spoken word recognition (e.g., McClelland & Elman, 1986), phoneme and word nodes are linked together by both excitatory and inhibitory connections. To aid selection, the activation of one node (e.g., dog) would lead to inhibition of the competitors (e.g., book). Phonological inhibition has previously been observed in a cohort priming study with 24-month-olds (Mani & Plunkett, 2011). The authors found that 24-month-olds failed to demonstrate target recognition if they have previously heard a cohort prime word, compared to a neutral prime word or no prime word. It is suggested that such inhibitory effect indicates that phonologically-similar words are linked in the infant lexicon, and that activation of one word node would lead to the inhibition of other phonologically-related ones. In the current experiment, both the cohort and rhyme distractors shared two phonemes with the target word, and could be seen as equally globally similar to the target word. As a result, the cohort and rhyme distractors may compete for selection by inhibiting each other, resulting in the lack of activation of both the cohort and rhyme distractors.

In contrast, 30-month-olds' fixation pattern resembled that of adults. It is possible that with greater amount of language experience, 30-month-olds have acquired more words and formed finer representations to discriminate between similar words (c.f. the lexical restructuring hypothesis by (Metsala & Walley, 1998). Compared to 24-month-olds, they may have perceived and analysed the incoming speech in finer segments. In fact, it has been shown that older children with language experience were less affected by the phonologically-similar distractor in the rhyme judgement task (J. M. Carroll & Snowling, 2001).

Another possibility is that 30-month-olds, with greater amount of language experience, have more knowledge and experience analysing the onset and rime constituents of words (Treiman et al., 1995).

To conclude, Experiment 4 demonstrates that, similar to adults, 30-month-olds demonstrated an early cohort preference and a late rhyme preference. In contrast, 24-month-olds showed no significant preference for either the cohort or rhyme distractors, which could be a result of mutual inhibition of the two, due to being equally globally-similar to the target word.

Part II

Language-Mediated Negative Priming

Chapter 7

Experiment 5: Negative Priming

7.1 Introduction

Part II of the thesis investigates how selective attention is driven by the interaction between the top-down semantics (e.g., an attentional set) and visual and auditory input, using a negative priming procedure with the visual world paradigm.

Selective attention refers to the selective processing of relevant information. A dominant view of the mechanism of selective attention is that selective attention is achieved by the amplification of the signals of the relevant information (e.g., a target picture) (e.g., Carrasco et al., 2002; Reynolds et al., 2000; Yeshurun & Carrasco, 1998). For example, in a selective attention study with fMRI, Egner & Hirsch (2005) presented participants with stimuli that consisted of a face, and a name in text which may or may not correspond to the face. Participants' task was to respond to either the face or the name, depending on the task instruction. The viewing of a face would typically activate the fusiform face area (FFA), while the viewing of text would typically activate the word form area. Both areas are located in the posterior cortex in the temporal lobe. The authors observed that, in incongruent trials (i.e., the face and name did not correspond), there was amplification of FFA signals when participants attended to the face and ignored the word. In contrast, there was no reduction of FFA signals when participants had to respond to the word and ignore the face. These findings support the view that selective attention is achieved by target amplification alone.

Another view of selective attention is the *dual mechanism*, that selective attention involves both amplification of the relevant information and inhibition of the irrelevant information (e.g., Houghton & Tipper, 1994, 1996; Kok, 1999; Neill & Westberry, 1987; Neumann & DeSchepper, 1991; Tipper, 1985; Woods, 1990). Inhibition of irrelevant information during selective attention has been extensively demonstrated in NP paradigms. NP refers to the impaired response observed when a participant has to respond to a stimulus feature or location that they previously ignored. The NP effect strongly suggests that selective attention involves inhibition of response towards the distractor.

In the following sections, I will review existing findings and theories of NP in adults, children and infants. I will then present Experiment 5, in which

I investigate how labelling as a language attentional set can drive toddler's visual selective attention. Specifically, by examining potential positive or negative after-effects of selectively attending a target location and/or identity, we could infer how top-down semantics interacts with bottom-up visual and auditory inputs: By target amplification or distractor inhibition, or both.

7.1.1 Negative Priming

NP was first observed in a colour stroop task. In Dalrymple-Alford & Budayr (1966) (Experiment 2), participants were presented with a sequence of colour words printed in incongruent ink colours (e.g., the word BLUE printed in red ink). Participants were required to name the ink colour, and ignore the printed word. Dalrymple-Alford & Budayr (1966) observed that participants' reaction time (RT) was impaired when they had to name an ink colour that was the ignored printed colour word in the previous trial.

NP has also been observed in tasks that manipulate the repetition of object identity and location. Identity NP was first observed by Tipper (1985), who showed participants superimposed line drawings in red and green colours. As shown in Figure 7.1, participants were instructed to attend and name the red target line drawing (shown here in solid lines), and ignore the green distractor line drawing (shown here in dotted lines) in two consecutive phases, termed the *prime phase* and *probe phase*. NP was observed in the *Ignored Repetition Condition*, when the prime distractor (the trumpet) became the probe target. Specifically, participants were slower and more erroneous to name the probe target than in the control condition. Similarly, as shown in Figure 7.2, location NP has been demonstrated when the probe target object appeared at the prime distractor location in the ignored repetition condition (Tipper et al., 1990, 1991).

Figure 7.1. Identity negative priming paradigm (Tipper, 1985). Superimposed line drawings in red (shown here in solid lines) and green (shown here in dotted lines) colours are presented. Participants are instructed to attend to the red target object and ignore the green distractor object in both the prime (top) and probe (bottom) phases. Negative Priming is observed in the ignored repetition condition, when the prime distractor (e.g., trumpet) becomes the probe target.

Figure 7.2. Location negative priming paradigm (Tipper et al., 1990). In both the prime and probe phases, participants are instructed to attend to the @ sign and ignore the + sign. Negative priming is observed when the probe target appears at the prime phase distractor (ignored) location in the ignored repetition condition.

7.1.2 Theories of Negative Priming

The two major theories of NP are distractor inhibition and episodic memory retrieval. The distractor inhibition theory proposes that NP results from the inhibition of the representations of the distractor features (Houghton & Tipper, 1994; Tipper, 1985). The episodic memory retrieval theory proposes that NP reflects the mismatch between the temporary episodic representations of the prime phase and probe phases.

Distractor Inhibition Theory

Tipper (1985) proposed that in order to facilitate selection of a target over a distractor, the attentional system inhibits responses to the distractor. NP observed in the ignored repetition condition reflects residual inhibition of the prime distractor representation. The distractor inhibition theory was later formally specified with a neural network model by Houghton & Tipper (1994). The authors proposed a model of selective attention that involves four sub-systems: 1) object field (bottom-up), 2) target field (top-down), 3) match/mismatch detector, and 4) response system. Bottom-up information of external stimuli (e.g., colour, identity, location, etc.) are represented in the object field, while top-down information of task goal (e.g., attend to red only) are specified in the target field. A matching process between the object and target fields takes place in the match/mismatch detector. Object field features that match with the specification of the target field would lead to further excitation of the matched features; while features that mismatch with the specification of the target field would lead to the inhibition of the mismatched features. Finally, nodes of features in the object field are linked to nodes of semantic categories. For example, the excitation of the feature nodes 'animate', 'four legs', and 'fur' would lead to the activation of the semantic category node of 'dog', but little activation to the node of 'book'.

Simulations of the ignored repetition condition suggest that NP reflects an initial activation disadvantage of the previously ignored stimulus. Figure 7.3 illustrates a simulation of the prime and probe phases in the control condition and the ignored repetition condition. In the control condition (left panel), the target and distractor in the prime phases were both activated initially at trial onset. While the prime target continued to reach significant amount of activation respectively, the prime distractor becomes inhibited. After prime stimuli offset, the prime target activation passively decayed, while the prime distractor suffers from an inhibitory rebound. In the probe phase, a new set of stimuli were presented, and therefore, residual inhibition of the prime distractor had no impact on the probe stimuli. In contrast, in the ignored repetition condition (right panel), the prime distractor was repeated as the probe target, while the probe distractor was a novel stimulus. The simulation results show that, despite recovering from inhibition, the previously ignored probe target suffers from an initial activation disadvantage compared to the novel probe distractor. It is, however, important to note that the probe target was not prevented from eventually reaching a significant amount of activation level for selection.

Figure 7.3. Simulations of negative priming Houghton & Tipper (1994). In the control condition (left panel), different stimuli were presented in the prime and probe phases. Therefore, residual inhibition of the prime distractor had no impact on the probe stimuli. In the ignored repetition condition (right panel), the prime distractor was repeated as the probe target, while the probe distractor was a novel stimulus. The simulation results show that, despite recovering from inhibition, the previously ignored probe target suffers from an initial activation disadvantage compared to the novel probe distractor.

Supporting evidence for the distractor inhibition theory includes the finding that NP diminishes when the prime target and distractor are clearly different and not competing for selection (Tipper, 1985). Tipper (1985) suggested that distractor inhibition depends on the participant's *selection state*: when it is difficult to select the target over the distractor, a high level of reactive inhibition towards the distractor is maintained during selection. In contrast, when it is easy to select the target over the distractor, there is no need to maintain reactive inhibition towards the distractor. Consequently, reactive inhibition towards the distractor will rapidly decline. The distractor inhibition theory is also supported by the finding of identity NP between semantically-related concepts, for example, ignoring the picture of a cat could impair subsequent response to the picture of a dog (Tipper, 1985; Tipper & Driver, 1988) or the word 'dog' (Tipper & Driver, 1988). These findings suggest that inhibition could spread between feature sharing concepts (Tipper, 1985; Tipper & Driver, 1988).

Episodic Memory Retrieval Theory

The episodic memory retrieval theory was developed based on Logan (1988)'s instance theory of automatisation, which postulates that each episode of our encounter with the visual world is stored in episodic memory, and that each episodic representation encodes both the stimulus and the associated response (e.g., we associate red light with the 'stop' response). When encountered with the same stimulus or response at a later instance, the relevant episodic representation is retrieved and leads to the generation of automatic behaviour (e.g., when we see a red light, we automatically stop). In regard to NP, Neill et al. (1992) proposed that NP results from conflicts between the prime phase stimulus-response association and the probe phase response goal. Specifically, the prime distractor to be ignored is encoded with a 'do-not respond' tag in the episodic representation. When the prime distractor becomes the probe target, the associated 'do-not respond' tag is retrieved and conflicts with the probe phase action, i.e., to respond. Such conflict leads to confusion and delayed response in participants. One line of evidence supporting NP as a memory phenomenon is that the NP effect is stronger when the prime and probe phases are similar. For example, a stronger NP effect has been observed when the prime and probe stimulus display had the same brightness intensity (Fox & De Fockert, 1998; Stolz & Neely, 2001).

Further evidence for the episodic memory retrieval theory comes from the finding that the strength of NP depends on how easy it is for one to discriminate between the pre-prime trial ($n-2$) and the prime trial ($n-1$), relative to discriminating between the prime trial ($n-1$) and the probe trial (n) (Neill et al., 1992)[1]. The effect of temporal discriminability can be illustrated with an experiment that has two 'response to stimulus intervals' (RSI, i.e., the time interval between response in a previous trial and the onset of stimuli in the next trial), for example, 500ms and 4000ms. When the two RSIs are randomised, the participant could encounter a short RSI (500ms) followed by a short RSI (500ms); a short RSI (500ms) followed by a long RSI (4000ms); a long RSI (4000ms) followed by short RSI (500ms); or a long RSI (4000ms) followed by a long RSI (4000ms). A *discrimination ratio* can be computed by dividing the pre-prime–prime RSI by the prime–probe RSI. Neill et al. (1992) demonstrated that the NP effect was strongest when the discrimination ratio was large ($4000ms/500ms = 8$): the pre-prime and prime events were temporally distant, while the prime and probe events were temporally close. As a result, the retrieval of prime event episodic representations was easy and discriminable from that of the pre-prime event. In contrast, the effect of NP was the weakest when the discrimination ratio was small ($500ms/4000ms = 0.125$): the pre-prime and prime events were

[1]see Baddeley (1976) for original proposal of the trace discrimination theory in memory recall tasks.

temporally close, while the prime and probe events were temporally distant. As a result, the retrieval of prime event episodic representations was difficult and easily confused with that of the pre-prime event. Finally, the NP effect was found to be equivalent when the discrimination ratio remained constant: short pre-prime–prime and prime–probe RSIs ($500ms/500ms = 1$), or long pre-prime–prime and prime–probe RSI ($4000ms/4000ms = 1$). The fact that the discrimination ratio of pre-prime–prime RSI and prime–probe RSI predicts NP strongly supports the contention that NP is a phenomenon of episodic memory retrieval.

Summary

So far, there is no resolution to this debate, as there is an increasing amount of research findings suggesting that NP is a complex phenomenon. Depending on the design of the task, NP could involve multiple mechanisms (see Fox, 1995; Frings et al., 2015, for complete reviews of NP studies). Tipper (2001) has attempted to merge together the two theories[2], but he has received little support from the literature, likely due to the lack of further evidence for the proposed merge. Nonetheless, the distractor inhibition and episodic memory retrieval theories remain important for our understanding of the phenomenon of NP.

[2] Tipper (2001) suggests that, on the one hand, the distractor inhibition focused on describing the encoding process in the prime phase, and assumed retrieval of this encoding in the probe phase. On the other hand, the episodic memory retrieval theory focused on explaining in what circumstances the prime phase episode may be retrieved, but made little specification of the encoding process, e.g., how exactly does a ‘do not respond’ tag work?

7.1.3 Development of Negative Priming

NP in children

Compared to adults, we know little about the development of NP during childhood. Tipper et al. (1989) (Experiments 1 and 2) first studied the effect of NP in 7-year-old children (and adults) using the stroop colour-word task, in which participants had to name the ink colour of a text, and ignored its content (which may be a colour word or XXXXs). As seen in Table 7.1, there were four conditions of ascending level of ink-word conflict: 1) neutral (a string of XXX); 2) repeated distractor (the same printed colour word in each list); 3) stroop control (colour word varies but not related to adjacent trials); 4) ignored repetition (colour word in prime trial becomes ink colour to name in probe trial). They predicted that higher ink-word conflict conditions are more difficult and would yield a longer RT in participants than lower conflict conditions. The effect of NP was assessed by comparing RT in the stroop control condition and the ignored repetition condition. Moreover, the effect of distractor interference was assessed by comparing participants' RT in the neutral condition with that in the stroop control condition. Tipper et al. (1989) found a significant NP effect only in adults, not in children. However, there was a significant distractor interference effect in both adults and children participants. The authors interpreted their findings as evidence that an inhibitory processing mechanism is not yet in place during childhood.

However, later studies using the same paradigm found that children as young as 5 years old show colour stroop NP effects comparable to older chil-

Table 7.1. Colour stroop conditions (Tipper et al., 1989). Participants had to name the ink colour, and ignore the text. Four conditions of ascending level of ink-word conflict: 1) neutral (a string of XXX); 2) repeated distractor (the same printed colour word in each list); 3) stroop control (colour word varies but not related to adjacent trials); 4) ignored repetition (colour word in prime trial becomes ink colour to name in probe trial).

Neutral	**Repeated Ignored**	**Stroop Control**	**Ignored Repetition**
XXX-g	BLUE-g	GREEN-r	BLUE-y
XXXXX-r	BLUE-r	BLACK-o	ORANGE-b
XXXXXX-o	BLUE-o	YELLOW-g	RED-o
XXXX-bk	BLUE-bk	BLUE-bk	BLACK-r
XXXXX-y	BLUE-y	ORANGE-y	GREEN-bk

Note. (b = blue, bk = black, g = orange, r = red, y = yellow).

dren and adults (Frings et al., 2007; Pritchard & Neumann, 2004, 2009). Moreover, Pritchard & Neumann (2011) provided direct evidence that the absence of NP effects in Tipper et al. (1989) was due to the manipulation of the ratio of high and low ink-word conflict trials. They found in 7-year-olds that the NP effect is intact when 100% of trials were high conflict (Experiment 1); however, the NP effect disappeared (Experiment 2) when there were 50% low conflict trials and 50% high conflict trials. These results, together with previous findings of a strong distractor interference effect in children (Tipper et al., 1989), suggest that NP effects in children are mediated by their ability to maintain a selection state. Pritchard & Neumann (2004) hypothesised that children's inability to maintain a focused selection state may arise from task boredom when the task is too easy in the low conflict trials. The empirical evidence so far suggests that the ability to maintain a selection state continues to develop during childhood (Pritchard & Neumann, 2011).

Other types of NP have also been studied in children. For example, Tipper et al. (1990) found that, despite having slower RTs, both 5- and 12-

year-old children and adults showed location NP effect. Similarly, Simone & McCormick (1999) demonstrated that children as young as 6 years old show effects of both location and identity NP, and its development was stable across children (6–11 years), younger adults (18–22 years) and older adults (60–82 years). Furthermore, the NP paradigm has been used to investigate the role of the inhibitory mechanism in various types of Piaget-style tasks, e.g., class inclusion (Borst et al., 2013; Perret et al., 2003), number not length (Houdeé & Guichart, 2001) and syllogistic reasoning (Moutier et al., 2006). Rather than the suppression of irrelevant stimuli properties or object identities, these studies examined the inhibition of irrelevant strategies.

NP in Infants

So far, only one research group has studied NP in infants. Amso & Johnson (2005, 2008) studied the emergence of location NP in 3-, 6- and 9-month-old infants using an eye-tracking paradigm. As shown in Figure 7.4, each trial included a prime phase and a probe phase, each lasting for 2000ms. In the prime phase, the infant participants saw a target (cartoon) and a distractor (grey square) appearing at two of the four locations. In the probe phase, participants saw only a target appearing at either the prime distractor location (repeated distractor trial, same as ignored repetition) or a new location (control trial). There was no explicit task, and the measurement was latency of saccade from the centre of fixation to the target.

They observed location NP in 9-month-olds, who were significantly slower to make a saccade to a probe target located at the prime distractor location, suggesting that response to the irrelevant location was impaired. Moreover, the NP effect in 9-month-olds was only captured when the prime-probe inter-stimulus interval (ISI)[3] was 200ms or 500ms, but not 67ms. In contrast, they found only a facilitation effect in 3- and 6-month-olds at 67ms and 200ms ISI, suggesting location NP emerges in the second half year of life. Moreover, the authors reported a greater distractor interference effect in 3-month-olds than 6- and 9-month-olds, suggesting that 3-month-olds were more easily distracted by the prime distractor and that attentional selection by inhibition is yet to fully develop during early infancy. Amso and colleague (Amso & Johnson, 2005, 2008) suggested that their results matched with the distractor inhibition theory (Tipper, 1985), that 9-month-old infants' impaired response in the ignored repetition condition was due to inhibition of the prime distractor location.

[3]Since there was no explicit response required from the infants, inter-stimulus interval (ISI) rather response-stimulus interval (RSI) was used.

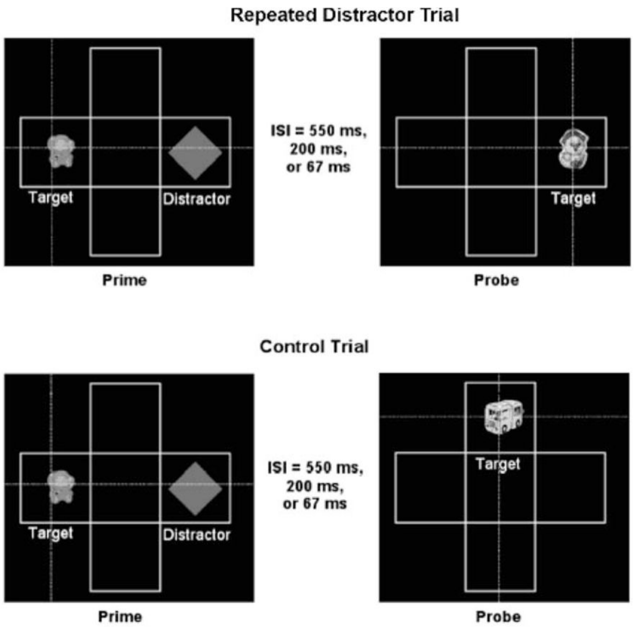

Figure 7.4. Infant location negative priming paradigm (Amso & Johnson, 2008). In the prime phase, infant participants saw a target (cartoon) and a distractor (grey square) appearing at two of the four locations. In the probe phase, participants saw only a target appearing at either the prime distractor location (repeated distractor trial) or a new location (control trial). Negative priming was observed in the repeated distractor trial.

7.2 NP Paradigm vs. Infant VWP Paradigm

The NP paradigm and the typical infant VWP study have a number of similarities. First, both involve repetition of stimuli in successive phases or trials. In the NP paradigm, stimuli are repeated in the prime and probe phases. In infant eye-tracking research, repetition of stimuli is a common practice. For example, in one trial, infants would be presented with the picture of a cow as the named target and the picture of a train as the unnamed distractor. In another trial, the same picture of a train would be presented as the named target, while the same picture of a cow would be presented as the unnamed distractor. Such counterbalancing procedure is termed yoking[4]. The aim of yoking in infant research is to cancel out potential response biases in the participant-averaged grand mean data. Previous research has shown that some infants, particularly younger ones, have a side bias for either the left or right side of the screen (e.g., Fisher-Thompson & Peterson, 2004). It is assumed that the yoking of picture location would eliminate potential side biases in the averaged data. Moreover, both infants and adults may have personal preferences for certain categories of objects, such as preferring animate objects (e.g., animals and vehicles) over inanimate objects (e.g., clothing). Yoking the role (e.g., as target or distractor) of each picture would allow us to eliminate potential biases. Furthermore, as infants have a limited vocabulary size, researchers often need to repeat the stimuli to construct more experimental trials. Yoking would avoid pure repetition of the trial. Despite the common practice of yoking, no infant study has systematically investigated the potential effects of repeating and counterbalancing picture role and picture location on infants' responses.

Second, in both NP and VWP studies, participants attend to a target and ignore a distractor. While children and adult participants in a NP study are assigned an attentional set either verbally or visually, infant participants

[4]The yoked control procedure was first used in operant conditioning experiments with animals (e.g., Skinner, 1938; Thorndike, 1898). In a typical operant conditioning experiment, the same reinforcement (e.g., food) is 'yoked' (paired up) with either the experimental contingency (e.g., food delivery is contingent on lever pressing) or control contingency (e.g., food delivery is not contingent on lever pressing). As the experimental and control conditions are identical except for the contingency manipulation, one can be confident that any behavioural differences in the two conditions reflect the effect of the contingency manipulation.

in a VWP study are automatically assigned an 'attentional set' by the target label. As demonstrated in Experiment 1 (and many other infant VWP studies), provided that the infant understands the label, they would attend to the named target significantly more than the unnamed distractor. In fact, a recent study has demonstrated that hearing an auditory label on top of a visual cue significantly improved 3-year-old children's search time in a visual search task (Vales & Smith, 2015). The main difference between NP and VWP studies is that while the majority of NP studies repeat only either the prime target or prime distractor, yoked trials in VWP studies tend to repeat both the target and distractor stimuli.

7.3 The Current Study

Part II of this thesis examines whether language-mediated visual attention during infancy involves both facilitation of target representations and inhibition of distractor representations. Specifically, Experiment 5 set out to investigate whether 24-month-old infants inhibit representations of irrelevant location and identity information during language-mediated visual attention in a NP-like setup. Previous children and adult NP studies(Simone & McCormick, 1999; Tipper et al., 1990, 1991) have demonstrated that participants inhibit response a a previously ignored location or object identity. Similarly, previous NP studies have demonstrated that infants develop the ability to inhibit response to an irrelevant location by the age of 9 months (Amso & Johnson, 2005, 2008). However, no studies have investigated whether infants inhibit response to an irrelevant object identity. Based on the dual-mechanism view, selective attention during language-mediated visual search would involve both amplification of relevant information and inhibition of irrelevant information. It was, therefore, predicted that infants in this study will show impaired target recognition in the probe phase, when the probe target location was previously ignored in the prime phase. Similarly, impaired target recognition was predicted when the probe target identity was previously ignored in the prime phase.

Figure 7.5 illustrates the timeline for one trial. Each trial began with a *prime phase*, in which participants saw a pair of pictures for 3000ms, and heard a phrase containing the target word (e.g.,"Look at the Cow"), with the onset of the prime target word always at 1500ms after pictures onset. Similarly, in the *probe phase*, participants saw a pair of pictures for 3000ms and heard a phrase containing the target word. The onset of the probe target word was always at 1500ms after target word onset. There was an inter-phase-interval (ISI) (a centre fixation dot on the screen) of 550ms between the prime and probe phases. The ISI duration was chosen based on the finding that 9-month-old infants only showed location NP when the ISI was 550ms, but not when it was 200ms or 67ms (Amso & Johnson, 2005, 2008).

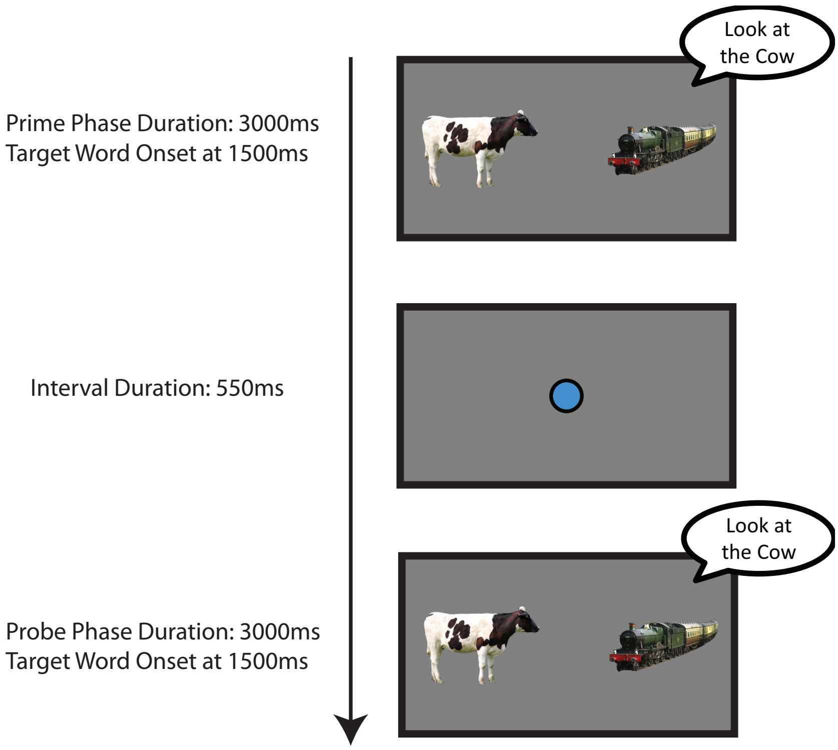

Figure 7.5. Timeline for a trial in Experiment 5.

Table 7.2. Six Conditions. The effect of location NP is compared in Conditions A and B. The effect of location and identity NP is compared in Conditions C to F.

Prime			***Probe***		***Target Location***	***Target Identity***
Cow	Train	*A.*	**Foot**	Stairs	Attended	Novel
Cow	Train	*B.*	Foot	**Stairs**	Ignored	Novel
Cow	Train	*C.*	**Cow**	Train	Attended	Attended
Cow	Train	*D.*	Train	**Cow**	Ignored	Attended
Cow	Train	*E.*	**Train**	Cow	Attended	Ignored
Cow	Train	*F.*	Cow	**Train**	Ignored	Ignored

Table 7.2 lists out the six conditions. The same prime stimuli are used to illustrate the six manipulations in the probe phase. The named target in each phase is indicated by **bold** font. In Conditions A and B, a novel pair of stimuli were presented in the probe phase. The probe target location was either attended or ignored in the prime phase. Location NP, as indicated by impaired probe phase target recognition was predicted for the ignored location condition (Condition B).

In Conditions C, D, E and F, the stimuli were repeated in the probe phase. In Conditions C and F, the stimuli remained in the same location in the prime and probe phases. In Conditions D and E, the stimuli swapped location in the probe phase. In Conditions C, both the probe target location and identity were attended. As a result, no NP was predicted for Condition C. In Condition D, the probe target location was ignored, while the probe target identity was attended. Therefore, only location NP was predicted in Condition D. In Condition E, the probe target location was attended, but the probe target identity was ignored. Only identity NP was predicted for Condition E. In Condition F, both the probe target location and identity were ignored. Both location and identity NP was predicted in Condition F. If location and identity NP effects were additive, one would predict the most amount of probe target preference in Condition C (attended location–attended identity), followed by Condition D (ignored location–attended identity) and E (attended location and ignored identity), and the least probe target preference in Condition F (ignored location–ignored identity).

7.4 Method

Participants

Thirty-two 24-months-olds (M_{age} = 24.6, age range = 23.52-27, Male = 19, Female = 13) were recruited from monolingual British households. No participant was excluded. This is because during data collection, this experiment was stacked at the end of another study. Participants only took part in this experiment if they were still concentrating after the first experiment.

7.4.1 Design

This was a within-subjects design. Each participant saw all six conditions for an equal number of times (four trials). The independent variables were the status of target location (attended vs ignored) and target identity (attended vs ignored). The measurement was duration of fixation towards the target during the pre-naming period (i.e before target word onset) and post-naming period (i.e., after target word onset) of the probe phase. Participants were randomly assigned to one of 12 lists (see Tables E2–E13 in Appendix E). The 12 lists served to counterbalance for trial condition, picture location and target naming between participants.

Each participant saw a total of 24 trials, which were presented in a pseudo-random order. As illustrated in Figure 7.5, each trial began with a 3000ms prime phase, during which participants saw a pair of pictures and heard a short phrase containing a target word, e.g.,"Look at the Cow". This was followed by an interval, in which an audio-visual attention getter was presented at the centre of the screen for 550ms. The purpose of the interval was to allow separation of the prime and probe phases. Finally, there was a 3000ms test phase. Similar to the prime phase, participants were presented a pair of pictures, and heard a short phrase containing a target word. For both the prime and test phases, target word onset was always at 1500ms after pictures onset. Between trials, a 1000ms flash animation was played to indicate a new trial.

7.4.2 Stimuli

As seen in Table E1 in AppendixE, 24 pairs of words were used as base pairs. In Conditions C to F, these base pairs were presented in both the prime and probe phases. In Conditions A and B in which there was no repetition, an extra eight pairs of words were used in the probe phase. The pictures were yoked so that each picture in each pair served as target and distractor equally often across participants. Each picture pair was used for each condition once between participants. The target and distractor in the prime and probe phases were dissimilar phonologically (i.e., they did not start with the same onset consonant or rhyme with each other), semantically (i.e., they did not belong to the same taxonomic category and were not associated according to the Edinburgh Associative Norms (Kiss et al., 1972), and visually (i.e., they did not have the same colour or were not easily confused with one another). Infants' preferences for animate objects was controlled: objects that move in real life (e.g., animals and vehicles) were paired together, while objects that do not move (e.g., clothing and food) were paired together.

The 64 words (ranging from one to three syllables) used in the experiment were chosen from the Oxford Communicative Development Inventory (OCDI) (Hamilton et al., 2000). Target words and pictures in the test trials were chosen based on the criterion that at least 60% of 24-month-olds were reported to understand the word.

Visual Stimuli

Realistic photographic representations were used. Objects were edited out of their original background, and placed in the centre of a $19.59 \times 19.59cm$ (50% grey) background using Adobe Photoshop. The two images were located in the middle-left and middle-right side of the screen, with a distance of $6cm$ ($5.27°$) away from each other. Across participants, each picture appeared on the left and right side of the screen equally often during the prime phase, and during the probe phase.

Auditory Stimuli

A female British Southern English speaker recorded the auditory stimuli in child-directed speech. In each trial, participants heard a sentence that included a prompt phrase followed by a target word, for example, "Look at the cow!". Mean duration of target words was $631ms$. Background noise and head and tail clicks were removed.

7.4.3 Procedure

Infants sat on their caregiver's lap approximately 65cm from the Tobii TX 300 eye tracker and a 23-inch screen of 1920 x 1080 screen resolution. The sampling rate was 120Hz. The caregiver was instructed to keep their eyes shut, remain quiet and refrain from any interactions with the infant during the experiment. A nine-point calibration was performed. The calibration attention getter was a colourful beach ball. The background colour of the screen remained grey throughout the experiment. Auditory stimuli were presented through a centrally located loudspeaker. In an adjacent room, the experimenter monitored the infant's eye movements. I monitored the participants' face through a centrally-located video camera above the screen. To achieve good calibration, individual locations were recalibrated when necessary. After calibration, infants were shown 24 trials. Each trial was initiated only when the infant was looking at the screen.

7.5 Results

There were in total 709 out of 768 trials available for analysis (on average 22 out of 24 trials per participant). Fifty-two trials (7%) were excluded because of the participants' unfamiliarity with pictures or words used. Seven trials (1%) were excluded due to zero looking time in the prime and/or post-naming phase. For the thirty-two participants included in the analysis, the averaged CDI receptive score was 348 words (SD = 70), and the averaged CDI expressive score was 264 (SD = 103). Participants understood on average 62 ($SD = 6$) out of the 64 words used in this experiment, and was able to say on average 55 ($SD = 15$) out of 64 words.

In the following sections, three types of analyses will be carried out. First, the *aggregated proportion of target fixations*, i.e., $Prop_{target}$ = Target / (Target + Distractor). This measurement would allow us to assess whether participants were 'on-task', i.e., their preference for the target picture before and after target label onset. Second, *time course of fixations.* As discussed in Chapter 2.2, eye-tracking data may follow different trajectories. Using growth-curve analysis, we will compare the time course of eye fixations between conditions. Third, *duration of the longest fixation* (DLF). DLF is an informative measurement additional to the time course, as it is independent of the baseline probability of fixation. In the post-naming window, the longest fixation is usually the first fixation after target label onset.

7.5.1 Location NP

Location NP was investigated in Conditions A and B. Participants saw a novel pair of stimuli in the probe phase. The probe target location was either attended or ignored in the prime phase.

Proportion of Target Fixations

Figure 7.6 shows a bar chart of participants' aggregated proportion of target fixations in the prime and probe phases, in the pre-naming (i.e., 1500ms before target label onset) and post-naming windows (i.e., 300–1500ms after target label onset)[5] in Condition A and Condition B. The error bars represent 95% confidence interval.

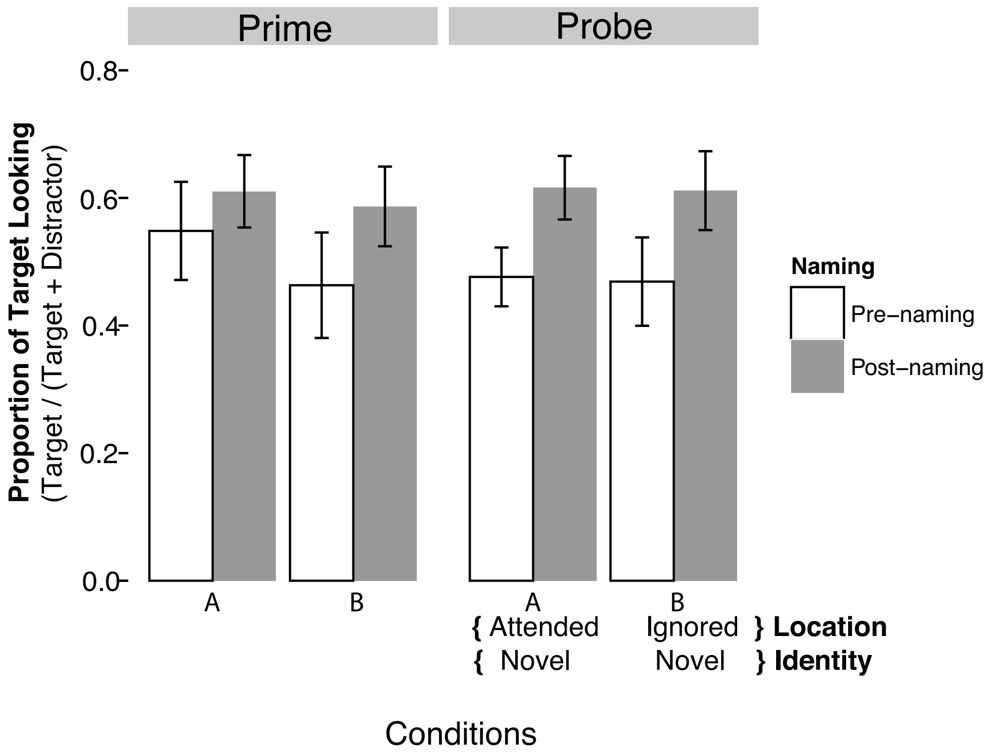

Figure 7.6. Aggregated proportion of target fixations in attended location condition (Condition A) and ignored location condition (Condition B) during the prime phase (left panel) and probe phase (right panel), in the pre-naming window (i.e., 1500ms before target label onset) and post-naming window (i.e., 300–1500ms after target word onset). Error bars represent 95% confidence interval. Statistical analyses indicate a significant target preference in both the prime and probe phase post-naming windows. However, there was no significant differences between the two conditions.

Prime Phase The purpose of the prime phase was to set up a scenario in which participants selectively attend to the named target picture. Selection of the target over the distractor would be indicated by a significantly greater

[5] As we are interested in language-mediated visual attention in the post-naming window, we took into account that it usually takes approximately 300ms for infants to make a saccade in response to the target label. Moreover, the time course graph in Figure 7.7 suggests that the time course of Conditions A and B began to differ at around 300ms after target label onset in both the prime and probe phases.

target preference in the prime post-naming window. As there was no manipulation in the prime phase, similar fixation patterns should be observed in the two conditions.

As seen in the left panel of Figure 7.6, in the *pre-naming* window, participants' target preference was at chance (i.e., 0.5) in both Condition A ($M = 0.55, t(31) = 1.33, p = .194$) and Condition B ($M = 0.46, t(31) = -0.931, p = .359$). In the *post-naming* window, participants' demonstrated a significant preference (i.e., above 0.5) for the target picture over the distractor picture in both Condition A ($M = 0.61, t(31) = 3.86, p = 001$) and Condition B ($M = 0.59, t(31) = 2.92, p = .006$).

A 2 (Window: Pre-naming vs. Post-naming) x 2 (Condition: A vs. B) repeated-measures ANOVA indicates a significant main effect of Window ($F(1, 31) = 10.12, p = .003$). This confirms that, compared to the pre-naming window, there was an increased target preference in the post-naming window. There was no significant main effect of Condition ($F(1, 31) = 1.70, p = .202$) or interaction of Window and Condition ($F(1, 31) = 1.23, p = .276$), indicating that the fixation patterns did not differ between the two conditions in the prime phase.

Probe Phase The purpose of the probe phase was to allow observation of potential location NP effects: the probe target appeared either at the attended location (Condition A) or ignored location (Condition B). The probe *pre-naming* window would allow observation of any *immediate after-effect* of distractor location inhibition during the prime phase. The probe post-naming window would allow observation of any language-mediated NP effects as a result of prime distractor location inhibition.

As seen in the right panel of Figure 7.6, in the *pre-naming* window, participants' target preference was at chance (i.e., 0.5) at both the attended location (Condition A: $M = 0.48, t(31) = -1.07, p = .194$) and ignored location (Condition B: $M = 0.47, t(31) = -0.90, p = .359$). In the *post-naming* window, participants demonstrated a significant target preference (i.e., above 0.5) at both the attended location (Condition A: $M = 0.62, t(31) = 4.77, p<.001$) and ignored location (Condition B: $M = 0.61, t(31) = 3.70, p<.001$).

A 2 (window: pre-naming vs. post-naming) x 2 (probe target location: attended vs. ignored) repeated-measures ANOVA indicates a significant main effect of window ($F(1, 31) = 18.56, p<.001$). This confirms that there was a significant increase in target preference in the probe post-naming window. There was no significant main effect of probe target location ($F(1, 31) = 0.047, p = .83$) or interaction of window and probe target location ($F(1, 31) = 0.004, p = .952$), indicating that fixation patterns did not differ between the two conditions in the probe phase.

In sum, the above analyses confirm that participants understood and responded to the target label in both the prime and probe phases. However, participants' probe phase target preference did not differ significantly at the attended location (Condition A) and the ignored location (Condition B). In other words, the measurement of proportion of target fixations suggests no evidence of location NP when the probe phase stimuli were novel.

Time Course

Figure 7.7 shows the time course of target fixation in the prime and probe phases, in the pre-naming and post-naming windows. Error bars represent 95% confidence interval.Similar to the aggregated proportion of target fixations data, the time course data suggest that participants showed an increased target preference in both the prime and probe post-naming windows.

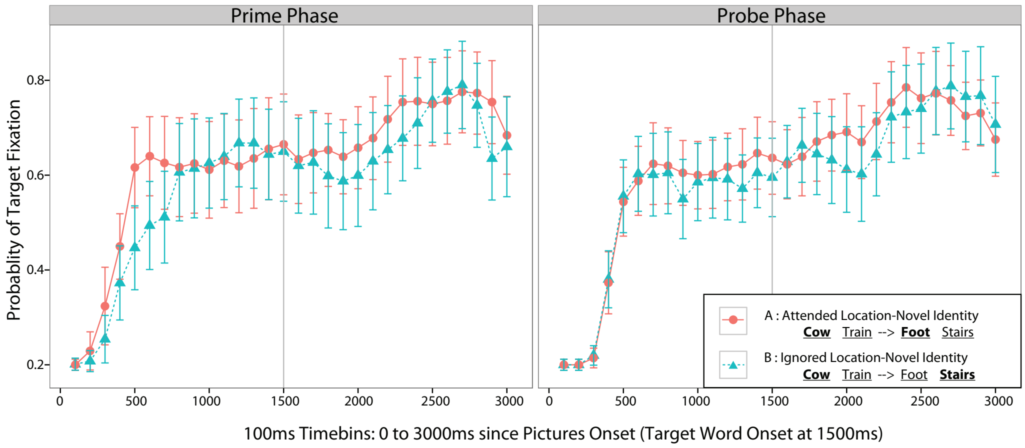

Figure 7.7. Conditions A and B. Time course of target fixations from 0 to 3000ms since pictures onset in the prime phase (left panel) and probe phase (right panel). Error bars represent 95% confidence interval.

Post-naming: Prime vs. Probe To examine whether the probe post-naming phase reflects any language-mediated NP effects as a result of distractor location inhibition, a growth curve analysis was performed to examine potential time course differences between the two conditions. The overall time course of fixations was captured by third-order orthogonal polynomials with fixed effects of probe target location (attended vs. ignored) and phase (prime vs. probe) on all time terms, and participant as random effects on the intercept and linear and quadratic terms. The attended location and the prime phase were treated as the baseline in the model, and relative parameters were estimated for the ignored location and the probe phase.

Figure 7.8 shows the data in points, and the growth curve model as lines. The data points suggest an earlier target preference at the attended location (Condition A) than the ignored location (Condition B). However, it is difficult to judge by eye whether there is any significant differences between the two conditions, and whether there were any differences between the prime and probe phases. Table 7.3 summarises the results of the statistical model. There was no significant effect of Condition, Phase, or interaction of Condition and Phase. In other words, the growth curve analysis suggests no significant location NP effect at the ignored location (Condition B).

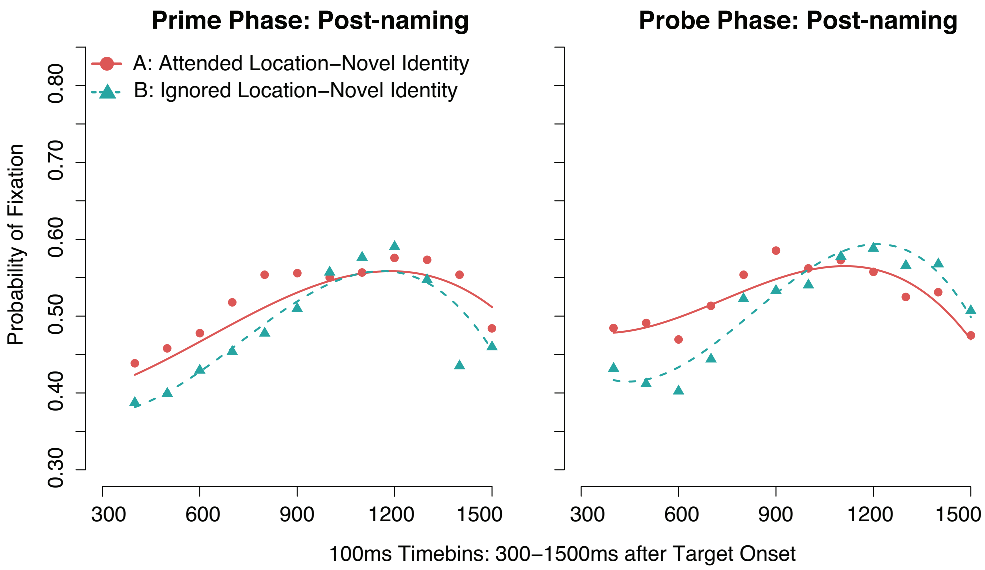

Figure 7.8. Growth Curve Analysis: Conditions A and B. The overall time course of fixations was captured by third-order orthogonal polynomials with fixed effects of probe target location (attended vs. ignored) and phase (prime vs. probe) on all time terms, and participant as random effects on the intercept and linear and quadratic terms. The attended location (Condition A) and the prime phase were treated as the baseline in the model, and relative parameters were estimated for the ignored location (Condition B) and the probe phase.

Table 7.3. Experiment 5–Attended Location (Condition A) vs. Ignored Location (Condition B): Growth Curve Analysis. Attended location and the prime phase were treated as baseline in the model, relative parameters were estimated for the ignored location and the probe phase fixation data.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Ignored Location (Condition B)	Intercept	-0.10 (0.07)	-1.44	.1486
	Linear	0.08 (0.23)	0.32	.7458
	Quadratic	-0.21 (0.23)	-0.89	.3741
	Cubic	-0.13 (0.23)	-0.56	.5765
Probe Phase	Intercept	0.05 (0.07)	0.74	.4572
	Linear	-0.35 (0.23)	-1.51	.1312
	Quadratic	-0.04 (0.23)	-0.20	.8449
	Cubic	-0.08 (0.23)	-0.34	.7309
Ignored Location*Probe Phase (Condition B)	Intercept	0.05 (0.09)	0.52	.6034
	Linear	0.49 (0.32)	1.50	.1327
	Quadratic	0.17 (0.32)	0.52	.6029
	Cubic	-0.03 (0.32)	-0.11	.9145

$***p<.001, **p<.01, *p<.05$

Duration of Longest Fixation

Figure 7.9 shows the duration of the longest fixation (DLF) in the pre-naming and post-naming windows in the prime and probe phases. Duration of the longest fixation is an informative measurement additional to the time course, as it is independent of the baseline probability of fixation. In the post-naming window, the longest fixation is usually the first fixation after target label onset. In Conditions A and B, 89% of the first fixation after target label onset was the longest fixation.

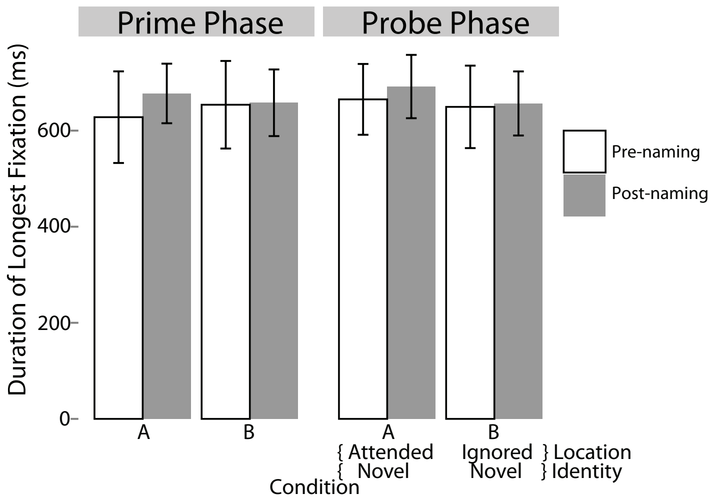

Figure 7.9. Duration of the longest fixation in the prime and probe phases, during the pre-naming window (i.e., 1500ms before target label onset) and post-naming window (i.e., 300-1500ms after target label onset) in Conditions A and B.

Here, we are interested in whether there is any significant differences in the probe post-naming window. Specifically, whether there is any significant differences between the DLF at the attended and ignored locations. A paired-sample t-test indicates no significant differences between the two conditions ($Mean_{difference} = 35.21, t(31) = 0.731, p = .4643$), suggesting no significant location NP effect at the ignored location (Condition B).

In sum, all three measures (proportion of target fixations, time course and duration of longest fixation) indicate no significant location NP effects when a novel probe target appeared at a previously ignored location.

7.5.2 Location and Identity NP

Location and Identity NP effects were investigated in Conditions C to F, in which the prime phase pictures were repeated in the probe phase. While the pictures were repeated in the same locations in Conditions C and F, the pictures were repeated in swapped locations in Conditions D and E. As a result, the probe target conditions were as follow: attended location–attended identity (Condition C); ignored location–attended identity (Condition D); attended location–ignored identity (Condition E); ignored location–ignored identity (Condition F).

Proportion of Target Fixation

Figure 7.10 shows a bar chart of participants' aggregated proportion of target fixations in the prime and probe phases, in the pre-naming and post-naming windows in Conditions C to F. The error bars represent 95% confidence interval.

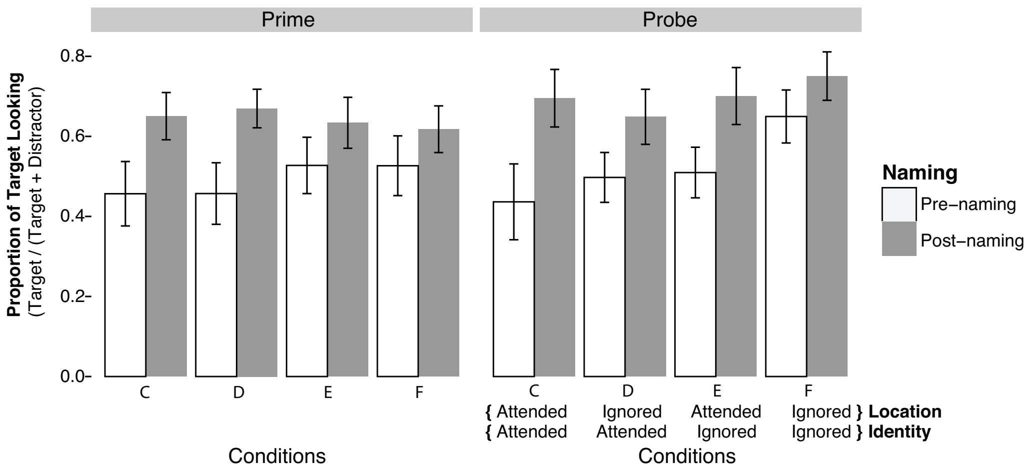

Figure 7.10. Aggregated proportion of fixations in Conditions C to F during the prime phase (left panel) and probe phases (right panel) during the pre-naming window (i.e., 1500ms before target word onset) and post-naming window (i.e., 300-1500ms after target word onset). Error bars represent 95% confidence interval.

Prime Phase The purpose of the prime phase was to set up a scenario in which participants selectively attend to the named target object. Selection of the target over the distractor would be indicated by a significantly greater target preference in the prime post-naming window. As there was no manipulation in the prime phase, similar fixation patterns should be observed in all four conditions.

As seen in the left panel of Figure 7.10, in the *pre-naming* window, participants' target preference was at chance (i.e., 0.5) in all four conditions: Condition C ($M = 0.46, t(31) = 1.12, p = .273$); Condition D ($M = 0.46, t(31) = -1.18, p = .248$); Condition E ($M = 0.53, t(31) = 0.82, p = .420$); Condition F ($M = 0.53, t(31) = 0.75, p = .457$). In the *post-naming* window, participants demonstrated a significant preference (i.e., above 0.5) for the target picture over the distractor picture in all four conditions: Condition C ($M = 0.65, t(31) = 5.23, p < .001$); Condition D ($M = 0.67, t(31) = 7.25, p < .001$); Condition E ($M = 0.63, t(31) = 4.20, p < .001$); Condition F ($M = 0.62, t(31) = 4.18, p < .001$).

A 2 (window: pre-naming vs. post-naming) x 4 (condition: C vs. D vs. E vs. F) repeated-measures ANOVA indicates a significant main effect of window ($F(1, 31) = 63.02, p < .001$). This confirms that there was increased target preference in the prime post-naming window. There was no significant main effect of condition ($F(1, 31) = 0.19, p = .902$) or interaction of window and condition ($F(3, 93) = 2.05, p = .113$), indicating that the fixation patterns did not differ between the four conditions in the prime phase.

Probe Phase The purpose of the *probe phase* was to allow observation potential location and/or identity NP effects. The *pre-naming* window allow observation of any *immediate after-effect* of distractor location and/or identity inhibition during the prime phase. The *post-naming* window would allow observation of any language-mediated NP effects as a result of distractor location and/or identity inhibition.

As seen in the right panel of Figure 7.10, in the *pre-naming* window, participants showed at-chance preference for three of the four conditions: the attended location–attended identity picture (Condition C: $M = 0.44, t(31) = -1.40, p = .173$), the ignored location–attended identity picture (Condition D: $M = 0.50, t(31) = -0.09, p = .932$) and the attended location–ignored identity picture (Condition E: $M = 0.46, t(31) = -0.99, p = .331$). In contrast, participants had a greater than chance preference for the ignored location–ignored identity picture (Condition F: $M = 0.65, t(31) = 4.61, p<.001$). In the *post-naming* window, participants' demonstrated a significant preference (i.e., above 0.5) for all four types of pictures: attended location–attended identity (Condition C: $M = 0.70, t(31) = 5.41, p<.001$), ignored location–attended identity (Condition D: $M = 0.65, t(31) = 4.36, p<.001$), attended location–identity identity (Condition E: $M = 0.70, t(31) = 5.89, p<.001$), ignored location–ignored identity (Condition F: $M = 0.75, t(31) = 8.52, p<.001$).

A 2 (window: pre-naming vs. post-naming) x 4 (condition: C vs. D vs. E vs. F) repeated-measures ANOVA indicates a significant main effect of window ($F(1, 31) = 62.87, p<.001$). This confirms that there was a significant increase in target preference in the probe post-naming window. There was also a significant main effect of condition ($F(3, 93) = 4.60, p = .005$). Post-hoc comparisons with Bonferroni adjustment indicate that regardless of window, there was significantly more fixations for the ignored location–ignored identity picture (Condition F) than the attended location–attended identity picture (Condition C: $M_{difference} = 0.13, p = .02$), the ignored location–attended identity picture (Condition D: $M_{difference} = 0.13, p = .024$) and the attended location–ignored identity picture (Condition E: $M_{difference} = 0.12, p = .015$). Moreover, there was a significant interaction of Window and Condition ($F(3, 93) = 2.98, p = .035$). Post-hoc comparisons indicate that fixations towards the ignored location–ignored identity picture (Condition F) in the probe pre-naming window was significantly greater than fixations towards the attended location–attended identity (Condition C: $M_{difference} = .21, t(31) = 3.42, p = .001$); the ignored location–attended identity picture (Condition D: $M_{difference} = .15, t(31) = 3.03, p = .005$)[6]; attended location–ignored identity picture (Condition E: $M_{difference} = .19, t(31) = 3.95, p < .001$). In contrast, the aggregated proportion of target preference did not differ significantly between conditions in the post-naming window (all ps $> .064$).

In sum, participants showed an increased target preference in both prime and probe post-naming windows. Interestingly, we observed a significantly greater preference for the ignored location–ignored identity picture (Condition F) in the probe pre-naming window. This indicates that participants preferred to attend to the prime distractor object identity that remained in

[6]Bonferroni corrected p value = .004, thus this difference is only marginally significant.

the same location in the probe phase. In the probe post-naming window, there were no significant differences between the four conditions. Contradictory to the predictions, the measurement of aggregated proportion of target fixations indicate no effect of distractor location or identity inhibition.

Time Course

Figure 7.11 shows the time course of target fixation in the prime and probe phases, in the pre-naming and post-naming windows. As seen in Figure 7.11a (left panel), during the prime phase, the fixation time course of the four conditions do not seem to differ in both the pre- and post-naming windows. In contrast, in the probe phase (right panel of Figure 7.11a), the time course data suggests differences between the four conditions. As confirmed in the aggregated proportion of target fixations analysis, participants had a significantly greater preference for the ignored location–ignored identity picture (Condition F) than the other three conditions during the probe pre-naming window. In the following section, we will examine whether the time course trajectories of the four conditions differ significantly during the probe post-naming window.

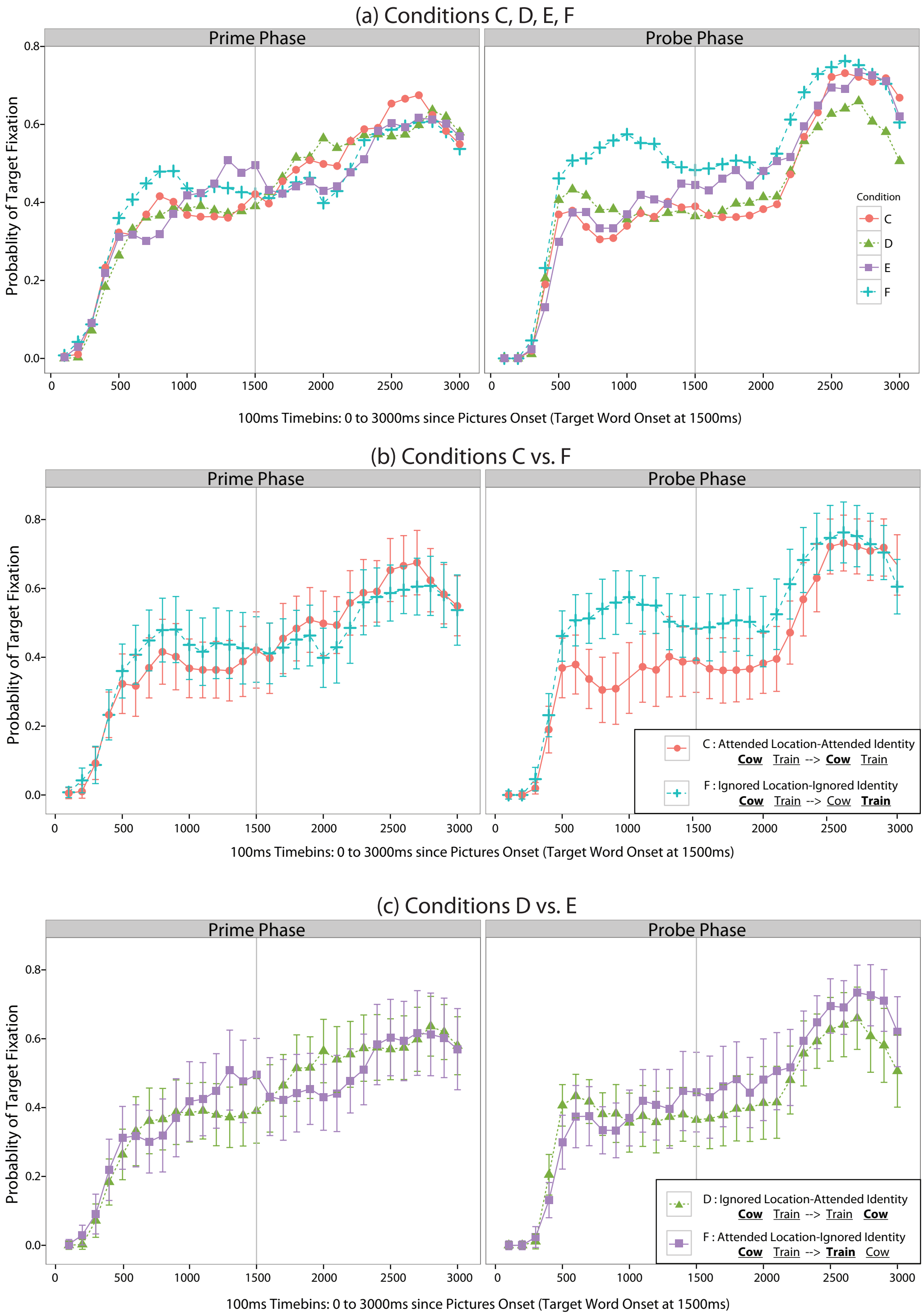

Figure 7.11. Timecourse of target fixation Conditions from 0 to 3000ms since probe phase pictures onset. a) Probe phase of Conditions C, D, E and F. b) Comparison of Conditions C vs. F: the pictures were repeated at the same locations. c) Comparison of Conditions D vs. E: the pictures were repeated but swapped locations.

Postnaming: Prime vs. Probe To examine whether the probe post-naming phase reflects any language-mediated NP effects as a result of distractor location and/or identity inhibition, a growth curve analysis was performed. The overall time course of fixations was captured by third-order orthogonal polynomials with fixed effects of condition (C vs. D vs. E vs. F) and phase (prime vs. probe), and participant as random effects on the intercept, linear and quadratic terms. Condition D (ignored location–attended identity)[7] and the prime phase were treated as the baseline in the model, and relative parameters were estimated for Conditions C, E, and F, and the probe phase.

Figure 7.12 shows the data in points, and the growth curve model as lines. The data points suggest different post-naming fixation patterns in the prime and probe phases. In the prime phase, the fixation trajectories are similar in all four conditions, and that the data points of all four conditions converge towards the end of the time course. In contrast, in the probe phase, participants seem to have a greater target preference in the ignored location–ignored identity condition (Condition F), followed by the attended location–attended identity condition (Condition C) and the attended location–ignored identity condition (Condition E). The data points of these three conditions reach a similar peak, and converge towards the end of the time course. Moreover, the data points suggest an overall greater amount of fixations in the

[7]Condition D (ignored location–attended identity) was chosen to be the baseline in the model because the time course graph suggests that there were less probe post-naming target fixation in Condition D than the other Conditions.

probe phase than in the prime phase for these three conditions (as indicated by higher peaks and steeper slopes). In contrast, the data points suggest that participants had the least amount of target preference for the ignored location–attended identity condition (Condition D). Moreover, there seem to be overall less amount of target fixation in the probe phase than in the prime phase (as indicated by lower baseline and peak of fixations).

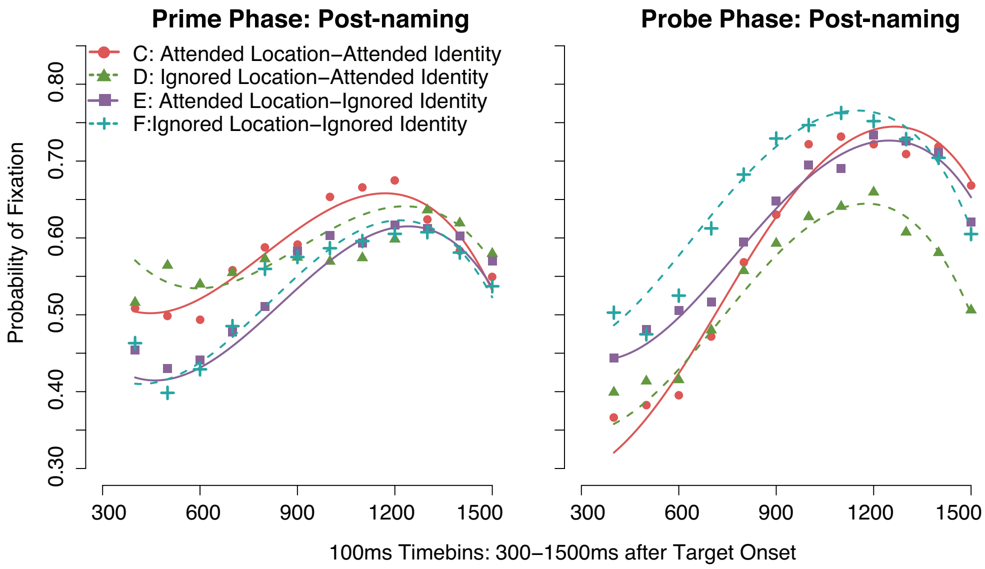

Figure 7.12. Growth Curve Analysis: Conditions C to F. The overall time course of fixations was captured by third-order orthogonal polynomials with fixed effects of condition (C vs. D vs. E vs. F) and phase (prime vs. probe), and participant as random effects on the intercept, linear and quadratic terms. Condition D (ignored location–attended identity) and the prime phase were treated as the baseline in the model, and relative parameters were estimated for Conditions C, E, and F, and the probe phase.

Table 7.4. Experiment 5–Conditions C to F: Growth Curve Analysis. Condition D (ignored location–attended identity) and the prime phase were treated as baseline in the model, relative parameters were estimated for Conditions C, E and F, and the probe phase fixation data.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Attended Location–Attended Identity (Condition C)	Intercept	-0.01 (0.07)	-0.19	.8525
	Linear	0.13 (0.25)	0.51	.6075
	Quadratic	-0.39 (0.25)	-1.54	.1241
Attended Location–Ignored Identity (Condition E)	Intercept	-0.26 (0.08)	-3.41	.0007***
	Linear	0.52 (0.26)	1.99	.0465*
	Quadratic	-0.23 (0.26)	-0.87	.3864
Ignored Location–Ignored Identity (Condition F)	Intercept	-0.24 (0.07)	-3.24	.0012**
	Linear	0.50 (0.25)	1.99	.0464*
	Quadratic	-0.36 (0.25)	-1.42	.1565
Probe Phase	Intercept	-0.23 (0.07)	-3.11	.0019**
	Linear	0.65 (0.25)	2.59	.0097**
	Quadratic	-0.69 (0.25)	-2.72	.0065**
Attended Location–Attended Identity (Condition C)*Probe Phase	Intercept	0.27 (0.10)	2.62	.0087**
	Linear	0.84 (0.36)	2.32	.0202*
	Quadratic	0.44 (0.36)	1.18	.2393
Attended Location–Ignored Identity (Condition E)*Probe Phase	Intercept	0.62 (0.11)	5.72	<.001***
	Linear	-0.23 (0.37)	-0.62	.5383
	Quadratic	0.50 (0.37)	1.35	.1780
Ignored Location–Ignored Identity (Condition F)*Probe Phase	Intercept	0.81 (0.10)	7.72	<.001***
	Linear	-0.59 (0.36)	-1.65	.1001
	Quadratic	0.20 (0.36)	0.54	.5877

$***p<.001, **p<.01, *p<.05$

Table 7.4 summarises the results of the statistical model. There was a significant effect of condition. Compared to the ignored location–attended identity condition (Condition D), participants had a significantly greater target preference (regardless of phase) in the attended location–ignored identity condition (Condition E) and the ignored location–ignored identity condition (Condition F) (see significant intercept and linear terms of Condition E and Condition F). However, target preference, regardless of phase, did not differ significantly between the ignored location–attended identity condition (Condition D) and the attended location–attended identity condition (Condition C).

There was also a significant effect of phase. Regardless of Conditions, participants showed greater amount of target fixations in the probe phase than in the prime phase (see significant intercept of Probe Phase). Moreover, the significant linear and quadratic terms indicate that the slope and curve of target fixation was steeper, and reached a higher peak in the probe phase than in the prime phase.

Finally, there were significant interactions of condition and phase. The significant intercept terms of the Condition C*phase, Condition E*phase and Condition F*phase interactions indicate that there were significantly less target fixation in the ignored location–attended identity (Condition D) in the probe phase than in the other three conditions. Moreover, the significant linear term of Condition C*Probe Phase indicates that a significantly steeper slope in the attended location–attended identity condition (Condition C) than in the ignored location–attended identity condition (Condition D). This is illustrated in the right panel of Figure 7.12: Despite having a lower baseline, fixations in attended location–attended identity condition (Condition C) increased at a faster rate than that in ignored location–attended identity condition (Condition D), and eventually reached the same height of peak as Conditions E and F. Detailed pair-wise comparisons of Conditions and Phase can be found in Appendix E.1.2.

In sum, the growth curve analysis indicates that there were significantly less target preference in the ignored location–attended identity condition (Condition D) than the other three conditions. In other words, we observe a location NP effect only when the identity was attended.

Duration of Longest Fixation

As there was a greater baseline preference for the ignored location–ignored identity picture (Condition F) during the probe phase pre-naming window, the duration of the longest fixation (DLF) measurement would allow us to examine any potential location and/or identity NP effects independent of the baseline probability of fixation. For Conditions C to F, 91% of the first fixation after target label onset was the longest fixation of the trial.

Figure 7.13 shows the DLF in the pre-naming and post-naming windows in the prime and probe phases. As seen in the left panel, the prime phase DLF data resembles that reported in the proportion of target fixation and time course analysis: DLF were similar in all four conditions in both the pre- and post-naming windows during the prime phase.

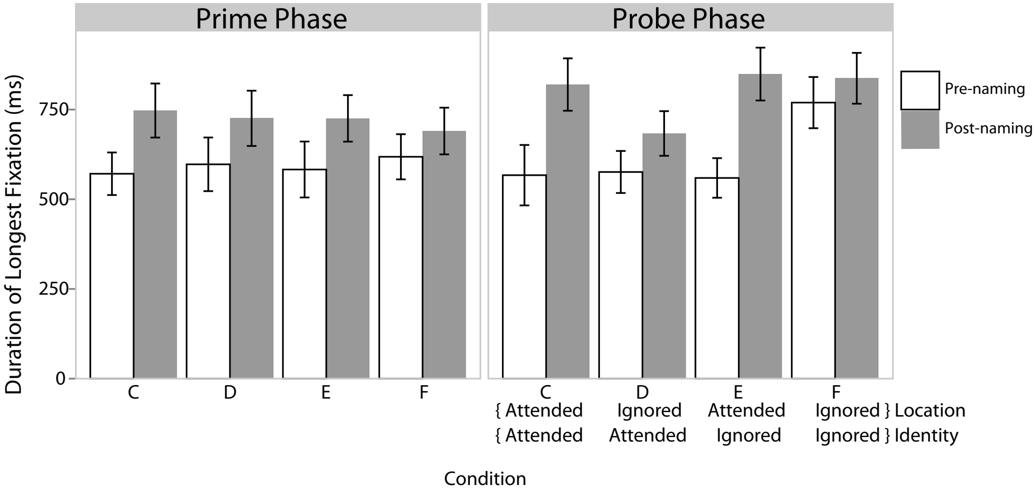

Figure 7.13. Duration of the longest fixation in the pre-naming and post-naming windows, in the prime and probe phases of Conditions C to F.

In contrast, the right panel of Figure 7.13 suggests that DLF differ between conditions in the probe phase. In the *probe pre-naming* window, DLF was longer in the ignored location–ignored identity condition (Condition F) than in the other three conditions. A 2 (probe target location: attended vs. ignored) x 2(identity: attended vs. ignored) repeated-measures ANOVA indicate that a significant main effect of probe target location ($F(1, 26) = 14.08, p = .001$), probe target identity ($F(1, 26) = 5.58, p = .026$) and interaction of probe target location and identity ($F(1, 26) = 5.363, p = .029$). Post-hoc pairwise comparisons with Bonferroni adjusted p value indicate that probe pre-naming DLF in the ignored location–ignored identity condition (Condition F) was significantly greater than the other three conditions: attended location–attended identity condition (Condition C: $M_{difference} = 196.13, p = .007$), the ignored location–attended identity condition (Condition D: $M_{difference} = 166.98, p = .008$), and the attended location–ignored identity condition (Condition E: $M_{difference} = 184.29, p<.001$).

In the *probe post-naming* window, DLF was shorter in the ignored location–attended identity condition (Condition D) than in the other three conditions. A 2 (probe target location: attended vs. ignored) x 2 (probe target identity: attended vs. ignored) repeated-measures ANOVA indicates a significant main effect of probe target location ($F(1, 93) = 4.43, p = .0381$), probe target identity ($F(1, 93) = 6.75, p = .0109$). There was a non-significant trend of interaction of probe target location and probe target identity ($F(1, 93) = 3.13, p = .08$). Post-hoc comparisons with Bonferroni adjusted p value confirm that the duration of the longest fixation in the ignored location–attended identity condition (Condition D) was significantly less than in the attended location–attended identity condition (Condition C: $p = .042$), the attended location–ignored identity condition (Condition E: $p = .007$), and the ignored location–ignored identity condition (Condition F: $p = .015$). There was no significant differences between Conditions C, E and F (ps $= 1$).

In sum, the measurement of DLF suggests a significantly greater preference towards the ignored location–ignored identity (Condition F) picture in the probe pre-naming window, and significantly less target preference for the ignored location–attended identity condition (Condition D) in the probe post-naming window.

Difference of Duration of Longest Fixation To further verify the DLF effect in the probe post-naming phase, here we will compare the post-naming DLF in the prime and probe phases. Figure 7.13 shows the difference between the probe post-naming DLF and prime post-naming DLF. A positive difference score indicates a longer DLF in the probe post-naming window than the prime post-naming window.

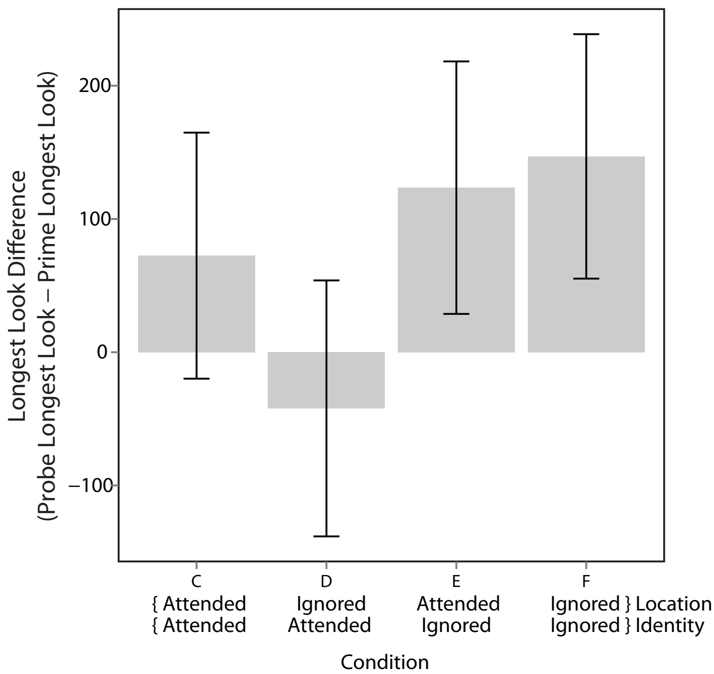

Figure 7.14. Difference of the duration of the longest fixation (DLF) in the prime and probe phases (i.e., Probe post-naming DLF minus prime post-naming DLF) in Conditions C to F.

The bar chart indicates that DLF increased in the probe post-naming window in the attended location–ignored identity condition (Condition C), the attended location–ignored identity location (Condition E) and the ignored location–ignored identity condition (Condition F), but decreased in the ignored location–attended identity condition (Condition D). A 2 (probe target location: Attended vs. Ignored) x 2 (probe identity: Attended vs. Ignored) repeated-measures ANOVA indicates a significant main effect of Identity ($F(1, 93) = 6.83, p = .0105$). There was no significant main effect of Location ($F(1, 93) = 0.98, p = .3239$) or interaction of Location and Identity ($F(1, 93) = 2.26, p = .1364$). Post-hoc comparisons (Bonferonni corrected p

value = .008) indicate that difference of DLF in ignored location–attended identity condition (Condition D) was significantly smaller than that of the ignored location–ignored identity (Condition F: $t(31) = -2.86, p = .028$), but did not differ significantly from that of the attended location–attended identity (Condition C:$t(31) = -1.81, p = .502$), and the attended location–ignored identity condition (Condition E: $t(31) = -2.45, p = .078$). There was no significant differences between Conditions C, E and F (all ps $>$.502). In sum, similar to the measurement of DLF, the difference of the prime and probe post-naming DLFs suggests impaired target processing in the ignored location—attended identity condition (Condition D) compared to the other three conditions. However, pairwise comparisons indicate significant differences only between Conditions D and F (ignored location–ignored identity).

In sum, the three analyses indicate that, in the probe pre-naming phase, participants demonstrated a preference for the ignored location–ignored identity picture (Condition F). In the probe pre-naming window, an identity-specific location NP effect was observed in the probe post-naming phase. Participants demonstrated a significantly smaller target preference in the ignored location–attended identity condition (Condition D) than the other three conditions. In other words, we observed location NP in Condition D, and no identity NP.

7.6 Discussion

This experiment set out to examine the potential location and identity NP effects in a two-picture visual world study. There were three main findings. First, no location NP effect was observed when novel probe stimuli were used in Conditions A and B. Probe phase target preference did not differ significantly at the attended location (Condition A) and the ignored location (Condition B). The findings of Conditions A and B do not fit with previous infant findings (Amso & Johnson, 2005, 2008) that, during selective attention, infants inhibit response to an irrelevant location. The lack of location NP effect in this experiment does not necessary prove the lack of inhibition of response to irrelevant information. However, I would like to point out that the finding of location NP in Amso & Johnson (2005, 2008) involved only the comparison of the ignored and neutral locations, but not the attended location. Therefore, their finding of a location NP effect could also be interpreted as a lack of preference for a familiar location. As the infant participants in Amso & Johnson (2005, 2008) were allowed $2000ms$ in the prime phase to freely look at the display, they were likely to have attended to both the prime phase target and distractor. The impaired response towards the prime distractor location could therefore be due to their greater preference for attending a new location. In order to verify this, Amso and Johnson would have to include the attended repetition condition (i.e., the probe target appearing at the prime target location). If the infant participants showed significantly faster RT in the attended repetition condition, Amso and Johnson could then confidently conclude that the prime distractor was inhibited in the prime phase. However, if their infant participants were equally slow to make a saccade to the prime target and prime distractor location, then their location NP finding were likely due to a novelty preference for a new location. Furthermore, the age group differences observed would instead reflect a developmental difference between novelty and familiarity preference (Hunter et al., 1983). For example, it has been demonstrated that when a task is difficult, younger infants prefer familiar stimuli while older infants prefer novel stimuli (Hunt, 1970).

Second, a *location-specific* preference for the ignored identity was observed in the pre-naming window in Conditions C to F, when the prime phase pictures were repeated in the probe phase, either at the same locations or swapped locations. As a result, the probe target location was either attended or ignored, and the probe target identity was either attended or ignored. Before the probe target was named (as seen in Figure 7.11b), participants showed a significantly greater baseline preference for the ignored identity (Condition F) over the attended identity (Condition C) when the object location–identity conjunction were congruent in the prime and probe phases. That is, they preferred looking at the prime distractor, an object they had seen before but did not have time to explore. However, such prime distractor preference disappeared when the objects have swapped location. As seen in Figure 7.11b, participants showed similar amount of preference for the attended and ignored identity (Conditions D and E). These findings suggest that the observed preference for the ignored identity observed in the probe pre-naming window was strongly influenced by the stimuli identity–location conjunction in the prime phase. I will discuss the role of identity–location binding in greater details in the Section 7.6.1.

Third, an *identity-specific* location NP effect was observed in the post-naming window in Conditions C to F. A location NP effect (a significantly smaller target preference) was observed only when the probe target identity was attended (Condition D: ignored location–attended identity), but not when the target identity was ignored (Condition F: ignored location–ignored location). Contradictory to my predictions, participants did not demonstrate identity NP. Instead, they had a strong preference for the previously ignored identity. The results are clearly shown in the growth curve analysis (see Figure 7.12). The fixation curves of the ignored location–attended identity (Condition D) reached a significantly lower peak than the other three conditions. Moreover, the duration of the longest fixation (DLF) in the probe post-naming window was significantly shorter in Condition D compared to the other three conditions (see Figure 7.13). The same pattern is also shown in the measurement of difference of the DLF in the prime and probe post-naming windows (see Figure 7.14.

The location NP effect observed in the ignored location–attended identity condition (Condition D) could be explained by both the distractor inhibition and episodic memory retrieval theories: the prime distractor location was inhibited or associated with a 'do not respond' tag. It is, however, peculiar that no location NP was observed in the ignored location–ignored identity (Condition F). A possible reason for the lack of location NP in the ignored location–ignored identity (Condition F) could be that participants' preference for the ignored identity overrode the location NP effect. As mentioned, participants had a greater baseline preference for the ignored location–ignored identity condition (Condition F) during the probe pre-naming window. In fact, previous NP studies have observed a strong distractor interference effect, that, sometimes, infant (Amso & Johnson, 2005, 2008) and children participants (Tipper et al., 1989) find it difficult to ignore the distractor in the NP task. Moreover, a novelty preference (that infants prefer novelty in comparison to a familiar stimulus that they are habituated with) is commonly observed and used to measure memory and learning outcome in infants (Hunter et al., 1983). As infants devoted most of their attention to the prime target, they were likely very keen to attend to the prime distractor in the probe phase.

In sum, the findings in Conditions C to F were unexpected. First, the location-specific preference for the ignored identity in the probe pre-naming window in Condition F strongly suggests that participants remembered the object identity–location conjunction during the prime phase, and detected a mismatch of these conjunctions when they have swapped. Second, it is surprising that participants' target preference was impaired only in the ignored location–attended identity condition (Condition D), but not in the ignored location–ignored identity condition (Condition F, which was predicted to be the most impaired in Condition due to potential location as well as identity

NP effects). In conclusion, the results strongly hint at object–location binding as the underlying mechanism of the effects observed in Conditions C to F. In the rest of the discussion, I will review recent infant and adult findings and theories of object identity–location binding, and discuss how they may provide alternative interpretations for the findings in Conditions C to F.

7.6.1 Object Identity–Location Binding

Research on object cognition during infancy has focused on *identification* ('What') and *individuation* ('Where') (Leslie et al., 1998). For example, Slater et al. (1991) using the habituation paradigm demonstrated that the ability to identify ('What?') objects is in place since birth. For example, newborn infants are capable of recognising stimuli based on the conjunction of two identity-defining object features (e.g., colour and shape). Recent studies have employed the brief occlusion paradigm to investigate the development of identification and individuation, and the conjunction of the two during infancy. The brief occlusion paradigm typically consists of a familiarisation and a test phase. During the familiarisation phase, participants see an object going behind an occluder at one location, and see another object going behind an occluder at a second location. In the test phase, the objects emerge from the occluders. Depending on the manipulation, the objects may or may not violate the object identity–location binding. Longer looking time in the violation conditions indicate surprise, and is usually interpreted as awareness of the object identity–location violation.

Studies using the brief occlusion paradigm have demonstrated that the ability to recognise objects by either their features or location is in place by four-months of age (Káldy & Leslie, 2003, 2005; Mareschal & Johnson, 2003; Newcombe et al., 1999; Tremoulet et al., 2000; Wilcox & Schweinle, 2002). For example, four-month-olds would look longer if there is a mismatch of object identity or location in the familiarisation and test phases (Mareschal & Johnson, 2003). Similarly, five-month-old infants would look longer if they saw a previously hidden object being retrieved from a location 20cm away from its hiding location (Newcombe et al., 1999). However, the *binding* of object identity and location information seem to only develop in the later half of the first year. For example, four- and five-month-olds did not show surprise when the object identity–location binding has been violated in the brief occlusion task (e.g., objects have swapped locations in the familiarisation and test phases) (Mareschal & Johnson, 2003; Newcombe et al., 1999). Káldy & Leslie (2005) found that 6.5-month-olds showed surprise to the violation of identity–location binding only when they had to track one object, but not when they had to track two objects. It was only until around 9-months that infants are able to simultaneously track the identity–location binding of two objects (Káldy & Leslie, 2003).

Object Files

Object identity–location binding has long been observed in adults. While Treisman & Gelade (1980)'s feature integration theory suggests that attention is necessary for forming coherent perception of objects with more than one features (e.g., colour, shape, orientation, etc.), Kahneman et al. (1992) extended the theory by proposing that the binding of object features and location are encoded into a temporary episodic representation, termed an 'object file'. When an object appears, it is determined as 'old' or 'new' in comparison to the existing object files. If the object is determined as new, a new object file is constructed based on the conjunction of object features and location. However, if the object is determined as old, the relevant object file will be retrieved. If there is a small change to an old object (e.g., same object features but changed location), the old object file will be retrieved, but will also require updating.

Supporting evidence of the encoding, and retrieval of object features and location was first observed in a letter naming experiment (Kahneman et al., 1992). In the preview phase, participants saw two different letters at two locations on the computer screen (e.g., letter V at location 1, letter Q at location 2). In the test phase, participants were to name a letter appearing at one of the two locations. Critically, the letter was either the same letter that had appeared at the same location in the preview phase (the same-object condition, e.g., letter V at Location 1); a letter that had appeared in the preview phase but at the other location (the different-object condition, e.g., letter Q at Location 1); or a letter they had not seen in the preview phase (the no-match condition, e.g., letter S at Location 1). Kahneman et al. (1992) found that, participants' letter-naming response was facilitated in the same-object condition compared to the different-object condition, suggesting an 'object-specific preview effect'. There was also a marginal facilitation effect in the different-object condition compared to the no-match condition, suggesting an 'object-nonspecific preview effect', that a *partial repetition* of the object-location conjunction could be beneficial. However, findings of the object-nonspecific preview effect has been inconsistent. While some studies found a partial-repetition benefit (i.e., facilitated response to a repeated stimulus at a different location) (Gordon & Irwin, 1996; Henderson, 1994; Henderson & Anes, 1994), other studies found a *partial-repetition cost* (i.e., no facilitation compared to the different-object condition) (Colzato et al., 2004; Hommel, 1998; Hommel & Colzato, 2004).

Park & Kanwisher (1994) has shown that Negative Priming (NP) could result from the mismatch of stimulus identity and location using a four-location NP paradigm. As seen in Table 7.5, their experiment had three ignored repetition conditions (i.e., the prime distractor became the probe target). The prime target was always the cross, and the prime distractor was always the circle. In reverse, the probe target was the circle and the probe distractor was the cross. In the symbol-match condition, the probe target appeared at the prime distractor (ignored) location. In the symbol-mismatch condition, the probe target appeared at the prime target (attended) location. In the control condition, the probe target appeared at a (neutral) location that was previously unoccupied by either shapes.

Table 7.5. The three ignored repetition conditions in (Park & Kanwisher, 1994). The prime target is the cross and the prime distractor is the circle. In reverse, the probe target is the circle and the probe distractor is the cross.

Stimulus/ measure	Condition		
	Control	Symbol-mismatch	Symbol-match
		Design	
Prime	. X . O	. X . O	. X . O
Probe	X . O .	. O X .	X . . O

The distractor inhibition theory would predict NP in the symbol-match condition due to inhibition of the prime distractor location, but no NP in the symbol-mismatch condition. In contrast, Park & Kanwisher (1994) proposed that NP would be observed when there is a mismatch of symbol and location conjunction. They predicted that NP would *not* be observed in the symbol-match condition because the same symbol occupied the same location in both phases, while NP would be observed in the symbol-mismatch condition due to symbol and location mismatch in the prime and probe phases. Interestingly, the results followed the predictions of Park & Kanwisher: RT in the symbol-match condition was significantly faster than in the control condition (i.e., facilitated response), while RT in the symbol-mismatch condition was significantly slower than in the control condition (i.e., location NP). Their findings suggest that, in this case, NP was not driven by distractor inhibition and that NP is not necessary a product of distractor inhibition or attentional selection in general. Instead, NP could reflect a partial-repetition cost of object features–location conjunction mismatch.

7.6.2 Object Identity–Location–Response Binding

While object files encode only the binding of stimulus and location, Hommel (1998) demonstrated that there is also binding of object-associated responses with that of object identity and location. In a series of left- or right-key response experiments, participants were shown either a vertical or horizontal bar at the top or bottom location of the screen. In a prime phase and a probe phase, participants had to press the left or right key based on either stimulus location or stimulus shape. For example, press the left key for the vertical shape, and vice versa. Depending on the manipulation, the response rule may remain identical or change in the probe phase. These experiments yielded two important findings. First, participants' response in the probe phase was facilitated if the object identity—responses conjunction in the prime phase was repeated in the probe phase. In contrast, their response was impaired when the target shape was repeated, but that the response was different (i.e., object identity–response conjunction violation). Second, they found an object-specific preview effect. Participants' response was facilitated when the object identity–location conjunction was repeated. In contrast, their response was impaired when there was a mismatch of the object identity–location conjunction. Furthermore, this kind of impairment was worse than that of object identity-response conjunction violation.

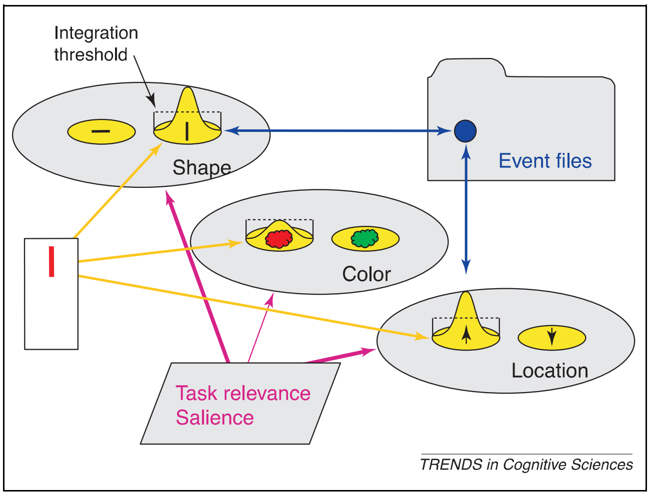

Figure 7.15. Event Files (Hommel, 2004). In this example, a red vertical bar appeared at the top location of the screen. Vertical shape, red colour and top location are all salient features to the task. However, only shape and location have a strong enough association with the task that they exceed the 'integration threshold' and become integrated and encoded into the event file. In contrast, the association between colour and task does not exeed the integration threshold for event file encoding.

Figure 7.15 illustrates how object features and location may be integrated into an event file (Hommel, 2004). This example illustrates a prime phase in which a red vertical bar appeared at the top location, and that stimulus shape determined participants' response (e.g., press left key for vertical bar). In this case, the vertical shape, top location, and red colour are all salient features to the task. However, only shape and location exceed the 'integration threshold' and become integrated and encoded into the event file. This is because shape determined the response, while location is strongly associated with the shape (as demonstrated by the object-specific preview effect), hence indirectly associated with the response. In contrast, the association between colour and response does not exceed the integration threshold for event file encoding. If, in the probe phase, participants sees a red vertical bar at the *bottom* location, the prime phase event file for the red vertical bar will be retrieved from episodic memory. However, since the retrieved event file encoded the prime phase shape–location conjunction (vertical and top location), the top location would be wrongly activated and consequently leads to delayed response to the bottom location.

The event file theory is not specific to NP, but could be seen as a variant of the episodic memory retrieval theory, in the sense that both take into account the encoding of object identity, location and response conjunction. However, Frings et al. (2015) point out that the original episodic memory retrieval theory (Neill & Valdes, 1992; Neill et al., 1992) implicitly assumes selection of the prime target over the prime distractor with a 'do-not respond' tag, while the event file theory emphasises that impaired response is due to the mismatch of the stimulus-response conjunction, and that encoding of the prime target and associated response, and the prime distractor are not necessarily separately. For example, it has been shown that the viewing of the prime distractor alone can lead to the retrieval of prime target response (Frings & Wühr, 2007; Giesen & Rothermund, 2014; Mayr & Buchner, 2006; Rothermund et al., 2005).

7.6.3 Interpretations of Conditions C to F Findings based on Object and Event Files theories

Probe Pre-naming Window: Identity–Location Mismatch

As seen in Figure 7.11b, during the probe pre-naming window, participants showed a significantly greater preference for the ignored location–ignored identity picture (Condition F) than the attended location–attended identity picture (Condition C). In other words, they showed a preference for the prime distractor in Condition F. However, this prime distractor preference disappeared when there was a mismatch of the object identity–location conjunction when the pictures have swapped locations in Conditions D and E. The lack of preference for the prime distractor at the attended location in Condition E could be explained by the effect of a *partial-repetition cost*. Based on the object file theory (Kahneman et al., 1992), one can assume that, the prime phase object file was retrieved in all four conditions. As the object–location binding was fully-repeated in Conditions C and F, the object files required no updating. However, the object–location binding was only partially repeated in Conditions D and E. Extra time was likely required for the participants to re-assess the display and update the prime phase object file. Therefore, participants did not spend more time exploring the ignored identity at the attended location (Condition E). In other words, the partial repetition incurred a *cost* on infants' visual processing of the display during the probe pre-naming window.

Probe Post-naming window: Identity–Location–Response Mismatch

The probe post-naming location NP findings in Conditions C to F cannot be explained by the object files theory alone. This is because, despite there was a mismatch of object identity–location binding in both Conditions D (ignored location–attended identity) and E (attended location–ignored identity), location NP was observed only in Condition D. However, the results can potentially be explained in terms of the event file theory, assuming that the location NP effect in Condition D was language-mediated.

Figure 7.16 illustrates my proposal. In the prime post-naming window, the target label, response identity and response location were encoded into an event file. In the probe post-naming window, the retrieval of the prime phase event file depended on the probe phase target label. In the attended identity conditions (Conditions C and D), participants heard the same target label which led to the retrieval of the prime phase event file. The prime phase event file leads to the activation of the prime phase response location and response identity. As the stimuli setup in Condition C (attended location–attended identity) matched with that encoded in the event file, target recognition was facilitated. In contrast, the stimuli setup in Condition D (ignored location–attended identity) was a partial-repetition, and did not match entirely with that encoded object identity–location conjunction in the event file. Specifically, the response location was not the same. As a result, target recognition was impaired. In the ignored identity conditions (Conditions E and F), the target label was different from that in the prime phase, hence no relevant event file was retrieved. As a result, the swapping of object locations in Condition E had no negative effect on target recognition. This explanation can account for the finding that, despite there was a violation of the prime phase object identity–location conjunction in Condition D (ignored location–attended identity) and Condition E (attended location–ignored identity), location NP effect was only observed in Condition D.

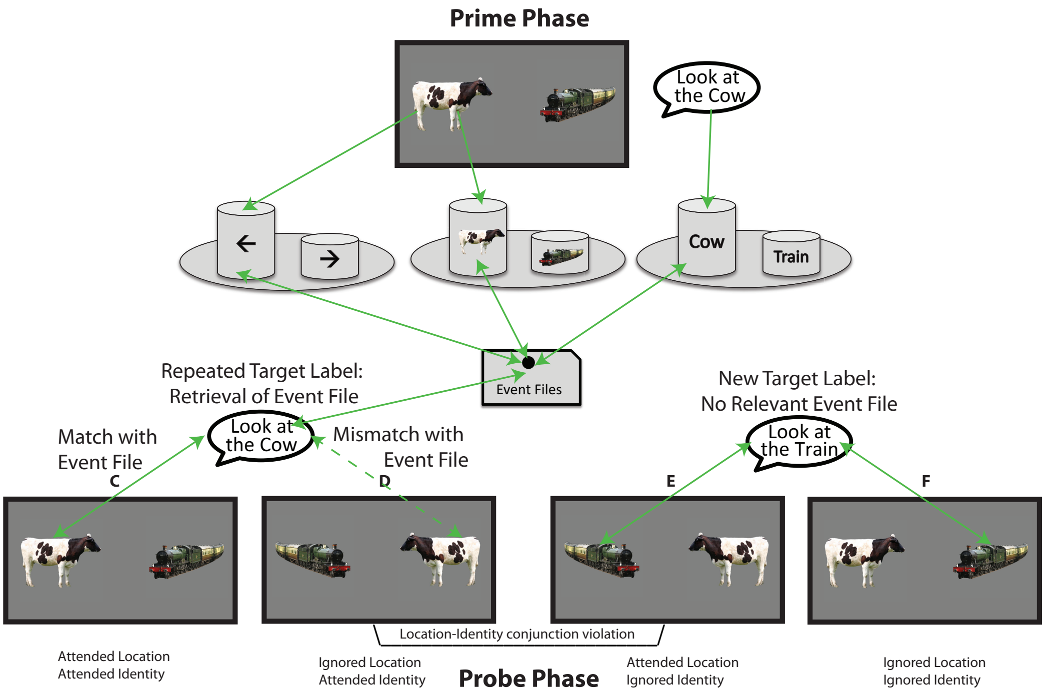

Figure 7.16. Results of Conditions C to F (post-naming) explained in terms of the encoding and retrieval of event files.

7.6.4 Conclusion

This study set out to investigate whether infants inhibit irrelevant location and identity information during selective attention in a language-mediated visual attention. When the probe phase stimuli were novel, we found no reliable location NP effect in 24-month-old toddlers. When the prime phase stimuli were repeated in the probe phase, we observed a preference for the ignored identity when the object identity–location conjunction was not violated. In the post-naming window, we observed a location NP effect only for the attended identity, but not for the ignored identity. Rather than distractor inhibition, these effects can be better explained in terms of the matching and mismatching of object identity–location–response bindings during the prime and probe phases. In fact, there is an increasing amount of research findings suggest that NP is a complex phenomenon. Depending on the design of the task, NP could involve multiple mechanisms (see Fox, 1995; Frings et al., 2015, for complete reviews of NP studies). In a book chapter titled 'In Opposition to Inhibition', MacLeod et al. (2003) argued that most evidence of cognitive inhibition, including NP, could be explained by alternative theories that are 'inhibition-free'. In conclusion, the findings of this experiment suggests that infants encode temporary episodic representations of object identity, location and associated responses within 1500–3000ms. These temporary episodic representations of past events are retrieved and compared with current events, and may influence language-mediated visual attention.

Chapter 8

General Discussion

8.1 Overview of Main Findings

Part I examined the time course and order in which phonological and semantic representations are retrieved and matched with audio and visual inputs during spoken-word recognition using the 'psycholinguistic approach' of the VWP.

Experiment 1 Experiment 1 was a first attempt in the thesis, as well as in the existing literature, to adapt the four-picture visual world paradigm (VWP) for infant testing. In Experiment 1, 24- and 30-month-old participants heard a target word (e.g. penguin) and saw four pictures: target (penguin), phonological distractor (pear), taxonomic distractor (tiger), and unrelated distractor (cot). The aim was to examine the potency of the phonological and taxonomic distractors, thereby gaining insights into the nature of the phonological and taxonomic representations that are activated when toddlers hear a word. A similar strategy was adopted by Huettig & McQueen (2007) in their investigation of adults. The results indicated that toddlers are capable of demonstrating target recognition when given a four-picture choice. There was also tentative evidence that participants treated the related and unrelated distractors differently. However, it was also evident that the majority of participants' attention was drawn to the target upon hearing the target label, leaving little room for the phonological and taxonomic distractors to play any substantial role in modulating infants' visual preferences.

Experiment 2 In Experiment 2, 24- and 30-month-old participants heard a target word and saw four pictures: phonological distractor, taxonomic distractor, and two unrelated distractors. Having excluded the target picture in order to boost the number of fixations towards the related distractors, Experiment 2 successfully demonstrated that there is generalised phonological and taxonomic activation during lexical access. Both 24- and 30-month-olds preferentially fixated the phonological distractor immediately after target word onset, reflecting early detection of a phonological match between the target word and the label associated with the phonological distractor picture. Moreover, they also preferentially fixated the taxonomic distractor, though somewhat later in the time course of the trial, reflecting a match between the taxonomic category associated with the target word and the taxonomic distractor, e.g., 'penguin' activates the taxonomic category *animal* leading to fixation of the picture of a tiger. Furthermore, we found that receptive vocabulary size, as opposed to age, was a better predictor of individual differences in this experiment. Participants with a larger vocabulary fixated the phonological distractor earlier and for a greater amount of time than those with a smaller vocabulary.

Experiment 3 The design of Experiment 3 was largely similar to that of Experiment 2, except that the taxonomic distractor was replaced with a thematic distractor. Moreover, the age criterion was relaxed to between 25- to 30-months in an attempt to cover a larger range of participant vocabulary size. The thematic distractor was defined as an object or context associated with the target (e.g., hair-brush). The results show that participants had an early preference for the phonological distractor, and a later preference for the thematic distractor. Similar to Experiment 2, participants with a larger expressive vocabulary had a more pronounced preference for both the phonological and the thematic distractors. Comparisons between Experiments 2 and 3 indicate that lexical-thematic relations may be acquired earlier and are more well-established than lexical-taxonomic relations. First, toddlers demonstrated a stronger preference for thematic distractors than for taxonomic distractors. Second, we found that expressive vocabulary size correlated with thematic fixations but not with taxonomic fixations, suggesting that thematic activation has a lexical basis, and perhaps that expressive vocabulary size is an indicator of the amount of opportunities for the lexical-semantic system to learn to associate two words.

Experiment 4 Experiment 4 compared 24- and 30-month-olds' preference towards two types of phonological distractors: cohort (i.e., same onset consonant and first vowel) and rhyme. Similarly to adults (Allopenna et al., 1998), 30-month-olds demonstrated an early preference for the cohort distractor and a late preference for the rhyme distractor. In contrast, 24-month-olds showed no significant preference between the cohort and rhyme distractors and the unrelated distractors. The lack of cohort and rhyme distractor preference in 24-month-olds was surprising, as previous research has shown that infants as young as 7.5 months are able to categorise on the basis of rhyme (Hayes et al., 2000), and that 24-month-olds demonstrate both cohort and rhyme words priming effects (Mani et al., 2012; Mani & Plunkett, 2011). I discussed the possibility of developmental differences in phonological processing in younger children (e.g., more global or holistic processing) and older ones (e.g., more local or segmented processing).

Part II set out to investigate how semantics can drive visual attention using the 'visual search approach' of the VWP. Based on the distractor inhibition theory, selective attention would be achieved through both target amplification and distractor inhibition (Houghton & Tipper, 1994; Tipper, 1985). Based on the episodic memory retrieval theory, attentional selection would be achieved by associating the distractor with a 'do not respond' tag. Both theories, however, have the same predictions in most experimental settings: impaired response would be observed when one has to respond to a previously irrelevant location or identity, owing to selection of the relevant information over the irrelevant information in a previous instance.

Experiment 5 Experiment 5 had six conditions. In Conditions A and B, 24-month-old toddlers saw two different pairs of pictures in the prime and probe phases, and one of the pictures was named. No reliable location NP effect was observed when the probe target appeared at the prime distractor (ignored) location. Such findings depart from the previous finding of location NP effect in 9-month-olds (Amso & Johnson, 2005, 2008). In Conditions C to F, participants saw the same pair of pictures in the prime and probe phases, either in the same locations, or in swapped locations. The probe target was either the prime target or the prime distractor. A complex interaction of location and identity NP was observed. No identity NP was observed. In contrast, participants showed a significantly greater preference for the prime distractor (i.e., the ignored identity) in the probe phase. In the probe *pre-naming* window, we observed a preference for the ignored identity at the ignored location. In the probe *post-naming* window, we observed a location NP effect only for the attended identity, but not for the ignored identity.

These findings were surprising and did not seem to reflect mechanisms of distractor inhibition. Instead, they reflect the encoding and retrieval of object identity–location–response bindings, and the matching and mismatching of these bindings during the prime and probe phases. More importantly, language played was responsible for the binding together object identity, location and response information.

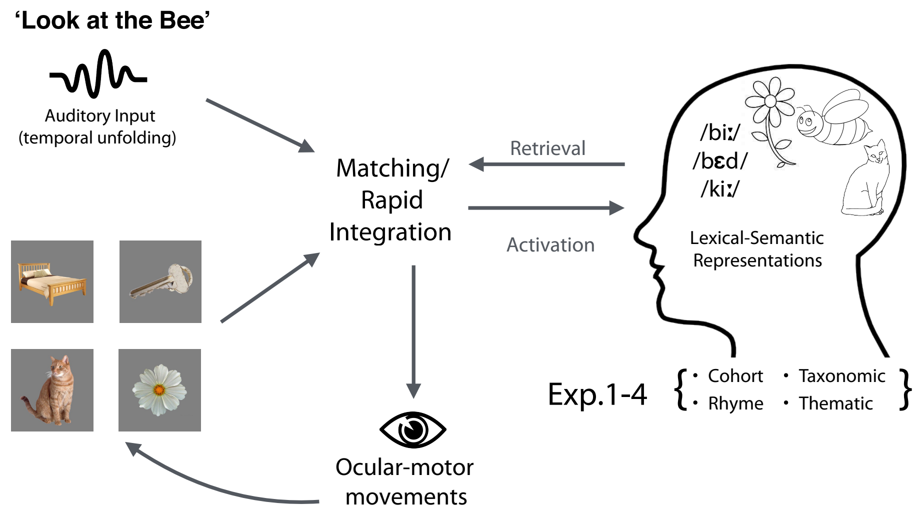

Figure 8.1. Thesis Part I. Part I demonstrated how relatively long-term lexical-semantic knowledge mediate visual attention.

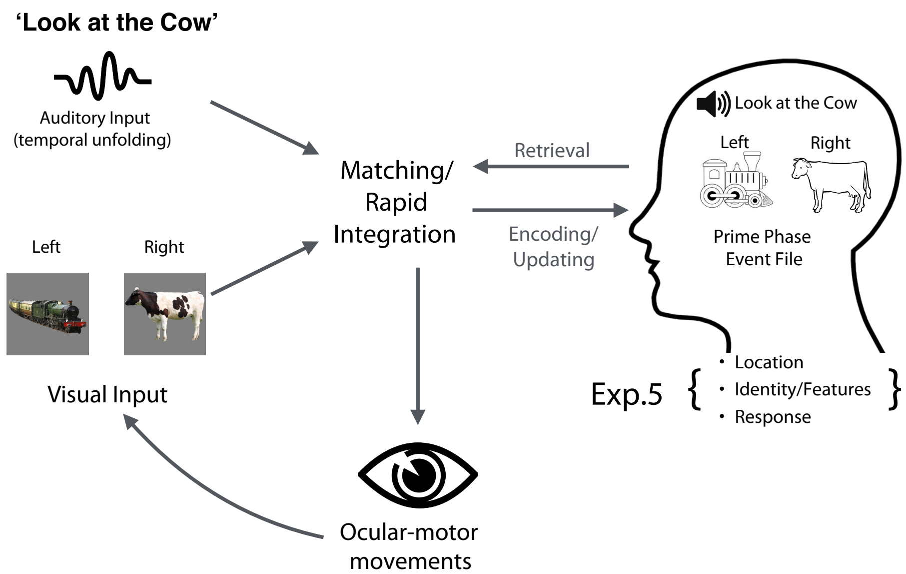

Figure 8.2. Thesis Part II. Part II demonstrated how recently encountered events are encoded into episodic representations, retrieved, and then mediate visual attention.

8.2 Implications

8.2.1 How Does Language Mediate Visual Attention?

The findings of this thesis demonstrate that there are at least two ways in which language can mediate visual attention. Figures 8.1 and 8.2 summarise the type of language-mediated visual attention observed in Experiments 1 to 4, and in Experiment 5 respectively. The findings in Part I and Part II were similar in the sense that both demonstrated that language-mediated visual attention involves the activation and retrieval of 'higher level' representations, which were then matched and integrated with the 'lower level' visual and auditory inputs. However, while Part I examined how relatively long-term lexical-semantic knowledge mediates visual attention, Part II demonstrated how recently encountered events are encoded into episodic representations by *language* (labelling). Specifically, language, as an attentional set, drives the encoding of object identity, location and response associations. Moreover, the retrieval of these associations rely on spoken-word recognition. The findings in Experiment 5 can also help us understand how long-term thematic or purely associative relations are formed. Words or labels not only represent taxonomic categories that are formed based on object feature similarities, but also thematic categories that are formed based on co-occurrences of events and objects. Together, the findings in Experiment 3 (Phonological vs. Thematic) and Experiment 5 suggest that labelling drives the formation of new associations.

8.2.2 Phonological vs. Semantic Distractors

In both Experiments 2 and 3 the named target referents were absent from the visual array for the critical test trials. A target-absent scenario is important because it allows potential relationships between the spoken word and other visual distractors to become apparent, unmasked by the attention attracting impact of the target itself. In both target-absent experiments, toddlers began to demonstrate an early preference for the phonological distractor over the unrelated distractor from around $300ms$ to $700ms$ after target word onset. However, fixation of the phonological distractor was short-lived. Toddlers' preference for the phonological distractor returned to baseline level within approximately $1000ms$ after target word onset. As attention towards the phonological distractor diminished, infants were drawn to the semantic distractors (either taxonomic or thematic) from around $750ms$ after target word onset. These results suggest that toddlers, like adults, extract phonological and semantic information from speech in an incremental fashion, leading to the automatic activation of unnamed but phonologically- and semantically-related items in the lexical-semantic system.

Traditionally, localist models of spoken-word recognition have assumed that phonological and semantic knowledge are represented at different levels in the lexical-semantic system, and that the access of knowledge at the phonological level precedes the semantic level (e.g., Marslen-Wilson, 1987; McClelland & Elman, 1986). However, the different time course of phonological and semantic activation can also be explained by a distributed model, in which phonological and semantic features are represented at the same level and can be activated simultaneously (Gaskell & Marslen-Wilson, 1997, 2002). For example, hearing the target word would lead to the activation of phonological and semantic features in parallel. As speech is processed incrementally, the activated phonological features tend to be more informative early in the time course. In contrast, semantic features would receive relatively weaker activation and ambiguous activation early in the time course, but become more informative later in the time course as the target word fully unfolded.

There was an overall smaller effect of phonological activation than taxonomic or thematic activation (see Figure 5.4). This may be due to the fact that compared to the phonological distractors, the taxonomic and thematic distractors were inherently more related to the target. As the cohort model predicts, candidate words that no longer match the target word become irrelevant as the target word unfolds (Marslen-Wilson, 1987). In contrast, the taxonomic and thematic distractors should become increasingly salient after the target word has fully unfolded, particularly in the absence of the named target. Furthermore, infants are likely to have greater semantic and conceptual knowledge than phonological knowledge. They show limited signs of word understanding before the age of one, and only become relatively proficient at producing words by the age of two. In contrast, infants acquire concepts long before they have the words for them. For example, infants as young as 3-months are able to categorise objects, such as animals and furniture, based on perceptual features (Eimas & Quinn, 1994; Eimas et al., 1994). By the age of two, infants have accumulated a great amount of conceptual information, involving colour, function and co-occurrence relations, and they are able to demonstrate their knowledge even if they do not yet have a word for it. For example, 24-month-olds look at a red object after hearing the word 'strawberry' (Johnson et al., 2011). Therefore, it is likely that the infant lexical-semantic system has stronger links formed on the basis of semantic relations than of phonological relations, resulting in a greater degree of semantic activation during spoken-word recognition.

8.2.3 Taxonomic vs. Thematic Distractors

Experiments 2 and 3 demonstrated that toddlers encode both taxonomic and thematic/associative information, respectively, in their lexical-semantic systems: Experiment 2 revealed a preference to fixate a taxonomically-related distractor over an unrelated distractor whilst Experiment 3 revealed a similar preference for thematically-/associatively-related distractors. Adult lexical-decision tasks have consistently shown strong priming effects for word pairs that are both associatively and semantically related (either taxonomic or thematic), but generally weaker priming effects for word pairs that are only semantically related (e.g., Fischler, 1977; Moss et al., 1995; Seidenberg et al., 1984; Shelton & Martin, 1992). In the adult neuroscience literature, there is evidence that taxonomic and thematic relations may be organised and accessed differently in the brain. For example, aphasic patients with semantic production errors make more taxonomic than thematic errors (Schwartz et al., 2009). Moreover, patients with lesions in the left anterior temporal lobe (ATL) make more taxonomic errors, while patients with lesions in the left temporoparietal junction (TPL) make more thematic errors (Schwartz et al., 2011). Sachs et al. (2008) found that adults showed no behavioural preference for taxonomic and thematic relations using the forced-choice triads task. Both types of semantic processing led to increased haemodynamic responses in the left inferior frontal, middle temporal and occipital regions. However, taxonomic relations required a greater amount of cerebral processing.

Plaut & Booth (2000) have shown that differences between associative priming and taxonomic priming effects in adults can be modelled using a distributed network model. According to their model, associative priming occurs because the lexical-semantic system has learned to associate the occurrence of one word/concept with another, and so, hearing one word leads to the automatic activation of the other. In contrast, categorical priming occurs because the prime word activates features that overlap with taxonomically-related concepts. Taxonomic priming effects tend to be less strong because non-shared features between the prime and target lead to inhibition. For example, butterflies have wings while tigers do not.

Our results with toddlers also suggest that the activation and retrieval of taxonomic and thematic/associative knowledge could be driven by distinct cognitive processes and/or that lexical-thematic relations are acquired earlier and are more well-established than lexical-taxonomic relations: Toddlers demonstrated a stronger preference for thematic distractors than for taxonomic distractors. Furthermore, we found that expressive vocabulary size correlated with thematic fixations but not with taxonomic fixations, suggesting that thematic activation has a lexical basis and perhaps that expressive vocabulary size is an indicator of the amount of opportunities for the lexical-semantic system to learn to associate two words.

8.2.4 Vocabulary Development and Phonological Sensitivity

In Experiments 1–3, we found that receptive vocabulary size predicts infants' preference for the phonological distractor, which shares only the same onset consonant as the target word. In Experiment 4, 30-month-olds demonstrated a preference for both the cohort and rhyme distractors, while 24-month-olds (with a significantly smaller vocabulary) showed no preference for either distractors. These findings indicate that the development of phonological sensitivity is related to the growth of the lexicon.

The lexical restructuring model (Metsala & Walley, 1998) proposed that, initially, infants form holistic (whole) lexical representations of words based on syllables or the overall acoustics. While older children and adults perceive speech by phonemic segments (e.g., consonant followed by vowel), newborns and young infants perceive speech in the unit of syllable (Bertoncini et al., 1988; Jusczyk & Derrah, 1987). However, word representations undergo phonemic segmentation (i.e., whole to part representation) as the infant lexicon acquires more words and requires finer representations to discriminate between similar words. There is evidence that older infants are, to some extent, sensitive to phonemic segmentation of words. Studies looking at novel word learning found that 17-month-olds (Werker et al., 2002), but not 14-month-olds (Stager & Werker, 1997), were incapable of pairing two phonologically similar novel words, e.g., bih and dih, to two different objects. Moreover, infants as young as 14-months are sensitive to mispronunciation of familiar words (e.g., baby vs vaby) (Swingley & Aslin, 2000, 2002). Swingley et al. (1999) showed that 24-month-old infants took longer to discriminate between words that start with the same onset consonant, e.g., doll and dog compared with doll and ball. Furthermore, Fernald et al. (2001) demonstrated that 18- and 21-months olds could identify a word after hearing only the first two phonemes.

The model proposed that lexical restructuring is driven by both global and local factors. Global factor refers to infants' overall vocabulary size. Infants' vocabulary increases greatly from around 18-months onwards (also known as the 'vocabulary spurt') (Benedict, 1979; Fenson et al., 1994; Goldfield & Reznick, 1990; Hamilton et al., 2000; K. Nelson, 1973) and continues to grow steadily in elementary school children (Anglin et al., 1993). Aside from the finding of the current study, there is ample evidence that age-related vocabulary growth is related to spoken-word recognition efficiency, for example, faster response speed and greater amount of target looking time during IPL spoken-word-recognition tasks (Fernald et al., 2006, 2001;

Zangl et al., 2005). Moreover, the emergence of an inhibitory phonological priming effect at 24-months, but not at 18-months, indicates that some form of changes takes place in the infant lexicon during this period of infancy (Mani & Plunkett, 2011).

Local factors refer to factors that influence the encoding or status of particular items in the lexicon, for example, word familiarity, frequency, age of acquisition, neighbourhood size, etc. Previous studies have shown that both adults and school children process words acquired at an earlier age more rapidly (J. B. Carroll & White, 1973; Newman & German, 2002). Moreover, neighbourhood size could have different effects depending on the task and population. Adult studies have demonstrated that words from high density neighbourhoods leads to facilitated responses in lexical decision and naming tasks (Andrews, 1989), but have inhibitory effects in speech recognition tasks (Dirks et al., 2001). Moreover, children were more accurate when naming words from high density neighbourhoods (Newman & German, 2002). During infancy, word learning is facilitated by a large neighbourhood size (Newman et al., 2008), but it could be disadvantaged if there is similarity with a well-known neighbour word (e.g. tog (dog) vs meb) (Swingley & Aslin, 2007). In the context of spoken-word processing, word recognition seems to be disrupted by large neighbourhood size in a priming paradigm (Mani & Plunkett, 2011).

Awareness of phonological representations is related to reading ability and is one of the best predictors of reading ability in early childhood (e.g. Hulme et al., 2002; Muter et al., 2004). The infant-adapted visual world paradigm developed in the current study has the potential to become a tool for predicting the development of phonological awareness in early childhood and may be relevant for intervention in language-related developmental disorders, e.g., developmental dyslexia and specific language impairment (SLI).

8.2.5 Locus of Word–Picture Matching

While the majority of VWP studies focus on lexical processing, few studies have investigated the manner in which high-level linguistic representations and low-level visual representations interact to drive visual attention.

Take Experiment 2 as an example: Toddlers' initial preference for the phonological distractor over the taxonomic distractor indicates that they access phonological information more quickly than semantic information during spoken word recognition. Word identification requires extraction of phonological information from the auditory signal before meaning can be accessed, so early preference for a phonological distractor over a semantically-related taxonomic distractor is perhaps not particularly surprising. However, it is instructive to enquire about the locus of the matching process between word and picture.

There are two possibilities: A *cohort* account and an *implicit-naming* account. On the cohort account, the listener constructs a phonological representation of the auditory signal which activates a range of lexical candidates that are gradually eliminated as word processing progresses to yield a single successful candidate consistent with the entire auditory signal (e.g., Marslen-Wilson, 1987). Consistent lexical candidates activate their corresponding semantic and perceptual representations, permitting a match with suitable visual stimuli. For example, upon hearing 'penguin', a cohort of lexical candidates, including 'pear' will be activated, supporting attention on the picture of the pear. Moreover, visual fixations of the pear are only likely to occur early in a trial as 'pear' will be swiftly eliminated from the cohort of lexical candidates as further information in the auditory channel is processed, and support for fixating the pear is thereby removed. Later fixation of the taxonomic distractor suggests that it takes more time to extract semantic information from the auditory signal and match this to the picture, and/or that the phonological 'pull' of the phonological distractor is stronger than the semantic 'pull' of the taxonomic distractor during the early stages of the trial. For example, late fixation of the tiger upon hearing 'penguin' can be explained by assuming that additional time is required for information about animacy to yield a match.

A second, *implicit-naming* account considers the possibility that pictures are implicitly named during the trial. There is ample evidence that implicit naming occurs in both adults (A. S. Meyer & Damian, 2007) and infants (Mani & Plunkett, 2010). Therefore, it is not unreasonable to suppose that some form of phonological code is available for each of the pictures in the display, particularly given that the listeners have several seconds to view them. From this viewpoint, the early orientation towards the phonological distractor is explained by the partial phonological match (at onset) between the auditory label and the implicitly-named phonological distractor. For example, upon seeing a pear the toddler implicitly names it thereby making its phonological code available to partially match the auditory input 'penguin'. The partial temporary match drives fixations to the pear until further auditory processing eliminates 'pear' as a candidate. This explanation appeals to the picture as the source of the name whereas the cohort account appeals to the heard auditory label as the source of the name (e.g., 'penguin' activates 'pear'). It is worth noting that Huettig & McQueen (2007) found that eliminating the preview period for the pictures also eliminated early preferential fixations towards the phonological distractor in their adult experiments. This finding is consistent with an implicit-naming explanation of early fixations of the phonological competitor: removing the opportunity to implicitly name the object undermines early matching with the heard auditory label. The *cohort* account is agnostic with respect to the length of the preview period.

Late fixations of the taxonomic distractor in the implicit-naming account might be explained by late-acting lexical-semantic links. For example, seeing a tiger activates the name 'tiger' which receives further support upon hearing 'penguin' through their proximity in the toddler's lexical-semantic network. This process must be weak or slow acting, or both, to explain late fixations relative to the phonological distractor. It is also possible that late fixations of the taxonomic distractor are driven by the extra time needed to extract semantic information from the auditory signal and match this to the picture, irrespective of the implicit naming of the taxonomic distractor. Future research could pin down the locus of the matching by reducing the pre-naming time, to cancel out implicit-naming opportunities.

8.3 Methodology and Limitations

In Part I of the thesis, I merged together the adult visual world paradigm (VWP) and the infant intermodal preferential looking (IPL) paradigm. As explained in Chapter 1.4, the rationale of the two paradigms is the same. However, previous infant IPL studies have been limited to using only two pictures owing to technological constraints (i.e., hand-coding of gaze direction before the invention of infant-friendly automated eye-trackers). Part I of this thesis demonstrates that, when combined with appropriate statistical methods, the adult four-picture VWP is suitable for infant testing. I was able to compare participants' preference for four pictures simultaneously, which is advantageous for studying the time course of the activations of multiple types of linguistic representations.

There were, however, drawbacks to using the VWP with infants. The infant vocabulary is limited and the use of four pictures means that more words had to be used than in a two-picture study. There was therefore a greater likelihood of participants not understanding the words in the experiment. As a result, more trials have to be excluded in a four-picture experiment than in a two-picture one. Moreover, yoking is more difficult with four pictures. As discussed in Chapter 7.2 in Part II of the thesis, yoking of stimuli role is an important procedure in infant testing. In Experiments 2 and 3, the picture role was yoked in each set of quadruples, e.g., each word was once the phonological distractor, taxonomic distractor, unrelated distractor 1, and unrelated distractor 2. Yoking the role (e.g., as target or distractor) of each picture would allow us to eliminate potential biases. However, given such stringent yoking, word choice is limited and the design process is time-consuming. For example, one of my undergraduate research students, Laura Brown, attempted to compare three types of target-related distractors simultaneously: phonological, taxonomic and thematic. It was almost impossible to yoke the stimuli as it is difficult to find enough words that infants understand and that are phonologically-similar, taxonomically-related as well as thematically-related to other words (e.g., it is difficult to define what the word 'key' may be taxonomically-related to). Likely due to the lack of stimuli yoking, participants showed a bias against the thematic distractor both before and after target label onset, making the data difficult to interpret.

In Part II of the thesis, I used a procedure that is similar to the typical negative priming paradigm. The methodological implication of the current findings is that repeating stimuli in successive trials could be detrimental to target recognition. If repetition is necessary in successive trials, it seems best not to violate the object identity–location conjunction within-participant. Counterbalancing the picture location between-participant would be a better alternative.

There are drawbacks to the design of Experiment 5. First, it is difficult to directly compare the current findings with existing NP findings, as a typical NP paradigm tends to repeat either the prime target or the prime distractor, while Experiment 5 either used novel stimuli or repeated both the prime target and prime distractor in the probe phase. Second, with hindsight, I should have used a four-location paradigm (e.g., in Park & Kanwisher (1994)). In this way, I would have been able to examine the effect of identity NP independent of object location, e.g., repeat an identity at a neutral location.

8.4 Future Directions

This thesis has demonstrated the speed with which toddlers are able to launch saccades and land eye fixations on pictures of named targets, or on pictures that are subtly related to a complex auditory stimulus, amongst a complex array of visual stimuli, attesting to a high degree of sophistication in the integration of meaningful auditory and visual signals. The infant-adapted visual world paradigm has the potential to become a powerful tool for streamlining the application of cognitive assessments and interventions in a very young population. For example, the visual world paradigm has been used to investigate individual differences in language processing in children and adults with developmental dyslexia, specific language impairment (SLI), and autism spectrum disorders (Andreu et al., 2011; Brock et al., 2008; Desroches et al., 2006). This study demonstrates that evaluations of this kind might be performed at a very young age indeed, perhaps providing a basis for early detection and intervention.

To a certain extent, the study of object features, location and response binding resembles that of operant conditioning (Skinner, 1938; Thorndike, 1898)–animals or human learning the association between stimulus, response and outcome. Gaining a better understanding of how language mediates the binding of object and event files in early childhood would provide us with valuable insights into how language directs learning in human beings, in comparison to animals which do not have language, but demonstrate visual selection. This may provide answers to the question of what makes human different from animals. Future research could explore whether infants encode identity, location, and response into a global event file, or separately into smaller event files for different purposes? What is the mechanism of encoding (e.g., visual indexing (Leslie et al., 1998; Pylyshyn, 2000) or correlation (Roelfsema et al., 1996; Singer & Gray, 1995))?.

8.5 Conclusion

This thesis examined how language mediates visual attention. Part I and Part II of thesis demonstrated that language-mediated visual attention involves the activation and retrieval of stored representations, which are then matched and integrated with visual and auditory inputs, which in turn drives visual attention. However, while Part I demonstrated how relatively long-term lexical-semantic knowledge mediates visual attention, Part II demonstrated how recently encountered events are encoded into episodic representations, retrieved, and mediate visual attention. Together, the thesis provides evidence that language plays an important role in mediating visual attention in toddlers.

Appendix A

Experiment 1

Table A.1. Experiment 1 stimuli yoke list.

Yoke Set	Target Word	Pictures			
		Target	*Phonological*	*Taxonomic*	*Unrelated*
1	Banana	Banana	Bicycle	Carrot	Turtle
	Bear	Bear	Bib	Snail	Cooker
	Biscuit	Biscuit	Boat	Chips	Frog
	Boots	Boots	Butterfly	Hat	Strawberry
	Chicken	Chicken	Chair	Cat	Tomato
	Crab	Crab	Cucumber	Pig	Bath
	Fridge	Fridge	Fish	TV	Car
	Helicopter	Helicopter	Horse	Bus	Cake
	Penguin	Penguin	Pear	Tiger	Cot
	Pushchair	Pushchair	Peas	Fire-engine	Cow
	Sock	Sock	Squirrel	Coat	Tractor
	Sofa	Sofa	Sandwich	Table	Bee
2	Bicycle	Bicycle	Boots	Pushchair	Tiger
	Boat	Boat	Bee	Car	Sock
	Cake	Cake	Cat	Sandwich	Bus
	Chair	Chair	Chips	Cot3	Snail
	Cow	Cow	Coat	Turtle	Biscuit
	Fish	Fish	Fire-engine	Butterfly	Cucumber
	Frog	Frog	Fridge	Horse	Carrot
	Pear	Pear	Pig	Strawberry	Helicopter
	Peas	Peas	Penguin	Banana	Hat
	Squirrel	Squirrel	Sofa	Crab	Bib
	Table	Table	Tractor	Bath	Chicken
	TV	TV	Tomato	Cooker	Bear
3	Bee	Bee	Biscuit	Cow	Sofa
	Bib	Bib	Bath	Sock	Cat
	Bus	Bus	Banana	Tractor	Penguin
	Carrot	Carrot	Car	Pear	Squirrel
	Cooker	Cooker	Crab	Fridge	Boots
	Cot	Cot	Cake	Chair	Butterfly
	Fire-engine	Fire-engine	Frog	Helicopter	Table
	Horse	Horse	Hat	Fish	Bicycle
	Pig	Pig	Pushchair	Chicken	Sandwich
	Strawberry	Strawberry	Snail	Cucumber	Boat
	Tomato	Tomato	Tiger	Peas	Coat
	Turtle	Turtle	TV	Bear	Chips
4	Bath	Bath	Bear	Sofa	Peas
	Butterfly	Butterfly	Bus	Squirrel	Pear
	Car	Car	Cow	Bicycle	Chair
	Cat	Cat	Cooker	Penguin	Fire-engine
	Chips	Chips	Chicken	Cake	TV
	Coat	Coat	Carrot	Boots	Horse
	Cucumber	Cucumber	Cot	Tomato	Pig
	Hat	Hat	Helicopter	Bib	Fish
	Sandwich	Sandwich	Sock	Biscuit	Crab
	Snail	Snail	Strawberry	Bee	Pushchair
	Tiger	Tiger	Table	Frog	Banana
	Tractor	Tractor	Turtle	Boat	Fridge

Table A.2. Experiment 1–Test List 1a. Trial order was randomized by the eye-tracking software.

List A1	*Picture Position*			
	Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Target Word	**Pictures (Picture Role)**			
Banana	Carrot (c)	Bicycle (p)	Turtle (u)	Banana (t)
Bear	Cooker (u)	Snail (c)	Bib (p)	Bear (t)
Biscuit	Biscuit (t)	Frog (u)	Chips (c)	Boat (p)
Boots	Hat (c)	Boots (t)	Butterfly (p)	Strawberry (u)
Chicken	Chicken (t)	Chair (p)	Tomato (u)	Cat (c)
Crab	Cucumber (p)	Bath (u)	Crab (t)	Pig (c)
Fridge	Fish (p)	Car (u)	TV (c)	Fridge (t)
Helicopter	Cake (u)	Helicopter (t)	Bus (c)	Horse (p)
Penguin	Penguin (t)	Pear (p)	Cot (u)	Tiger (c)
Pushchair	Fire-engine (c)	Cow (u)	Pushchair (t)	Peas (p)
Sock	Coat (c)	Squirrel (p)	Sock (t)	Tractor (u)
Sofa	Sofa (t)	Table (c)	Sandwich (p)	Bee (u)

Note: t = target, p = phonological distractor, c = taxonomic distractor, u = unrelated distractor.

Table A.3. Experiment 1–Test List 1b. Trial order was randomized by the eye-tracking software.

List A2	*Picture Position*			
	Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Target Word	**Pictures (Picture Role)**			
Banana	Banana (t)	Bicycle (p)	Carrot (c)	Turtle (u)
Bear	Bear (t)	Snail (c)	Cooker (u)	Bib (p)
Biscuit	Frog (u)	Chips (c)	Boat (p)	Biscuit (t)
Boots	Butterfly (p)	Hat (c)	Boots (t)	Strawberry (u)
Chicken	Cat (c)	Tomato (u)	Chicken (t)	Chair (p)
Crab	Pig (c)	Crab (t)	Bath (u)	Cucumber (p)
Fridge	Fridge (t)	Car (u)	Fish (p)	TV (c)
Helicopter	Cake (u)	Horse (p)	Helicopter (t)	Bus (c)
Penguin	Pear (p)	Tiger (c)	Cot (u)	Penguin (t)
Pushchair	Cow (u)	Pushchair (t)	Peas (p)	Fire-engine (c)
Sock	Squirrel (p)	Sock (t)	Coat (c)	Tractor (u)
Sofa	Sandwich (p)	Bee (u)	Table (c)	Sofa (t)

Note: t = target, p = phonological distractor, c = taxonomic distractor, u = unrelated distractor.

Table A.4. Experiment 1–Test List 2a.Trial order was randomized by the eye-tracking software.

List B1	*Picture Position*			
	Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Target Word	**Pictures (Picture Role)**			
Bicycle	Tiger (u)	Bicycle (t)	Pushchair (c)	Boots (p)
Boat	Boat (t)	Sock (u)	Car (c)	Bee (p)
Cake	Bus (u)	Sandwich (c)	Cake (t)	Cat (p)
Chair	Cot (c)	Chips (p)	Snail (u)	Chair (t)
Cow	Coat (p)	Cow (t)	Biscuit (u)	Turtle (c)
Fish	Fish (t)	Fire-engine (p)	Cucumber (u)	Butterfly (c)
Frog	Fridge (p)	Carrot (u)	Frog (t)	Horse (c)
Pear	Pig (p)	Helicopter (u)	Strawberry (c)	Pear (t)
Peas	Peas (t)	Banana (c)	Penguin (p)	Hat (u)
Squirrel	Bib (u)	Crab (c)	Sofa (p)	Squirrel (t)
Table	Bath (c)	Tractor (p)	Table (t)	Chicken (u)
TV	Cooker (c)	TV (t)	Tomato (p)	Bear (u)

Note: t = target, p = phonological distractor, c = taxonomic distractor, u = unrelated distractor.

Table A.5. Experiment 1–Test List 2b. Trial order was randomized by the eye-tracking software.

List B2	*Picture Position*			
	Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Target Word	**Pictures (Picture Role)**			
Bicycle	Tiger (u)	Boots (p)	Bicycle (t)	Pushchair (c)
Boat	Sock (u)	Bee (p)	Car (c)	Boat (t)
Cake	Bus (u)	Cake (t)	Cat (p)	Sandwich (c)
Chair	Chair (t)	Chips (p)	Cot (c)	Snail (u)
Cow	Turtle (c)	Biscuit (u)	Coat (p)	Cow (t)
Fish	Fire-engine (p)	Butterfly (c)	Cucumber (u)	Fish (t)
Frog	Horse (c)	Frog (t)	Carrot (u)	Fridge (p)
Pear	Pear (t)	Helicopter (u)	Pig (p)	Strawberry (c)
Peas	Banana (c)	Hat (u)	Penguin (p)	Peas (t)
Squirrel	Squirrel (t)	Crab (c)	Bib (u)	Sofa (p)
Table	Tractor (p)	Table (t)	Bath (c)	Chicken (u)
TV	Tomato (p)	Cooker (c)	TV (t)	Bear (u)

Note: t = target, p = phonological distractor, c = taxonomic distractor, u = unrelated distractor.

Table A.6. Experiment 1–Test List 3a.Trial order was randomized by the eye-tracking software.

List C1	*Picture Position*			
	Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Target Word	**Pictures (Picture Role)**			
Bee	Biscuit (p)	Bee (t)	Sofa (u)	Cow (c)
Bib	Sock (c)	Bib (t)	Bath (p)	Cat (u)
Bus	Bus (t)	Penguin (u)	Tractor (c)	Banana (p)
Carrot	Pear (c)	Car (p)	Carrot (t)	Squirrel (u)
Cooker	Boots (u)	Fridge (c)	Cooker (t)	Crab (p)
Cot	Chair (c)	Cake (p)	Butterfly (u)	Cot (t)
Fire-engine	Table (u)	Fire-engine (t)	Helicopter (c)	Frog (p)
Horse	Bicycle (u)	Fish (c)	Hat (p)	Horse (t)
Pig	Pig (t)	Pushchair (p)	Sandwich (u)	Chicken (c)
Strawberry	Strawberry (t)	Cucumber (c)	Snail (p)	Boat (u)
Tomato	Tiger (p)	Coat (u)	Peas (c)	Tomato (t)
Turtle	TV (p)	Chips (u)	Turtle (t)	Bear (c)

Note: t = target, p = phonological distractor, c = taxonomic distractor, u = unrelated distractor.

Table A.7. Experiment 1–Test List 3b. Trial order was randomized by the eye-tracking software.

List C2	*Picture Position*			
	Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Target Word	**Pictures (Picture Role)**			
Bee	Cow (c)	Sofa (u)	Bee (t)	Biscuit (p)
Bib	Bath (p)	Sock (c)	Bib (t)	Cat (u)
Bus	Penguin (u)	Banana (p)	Tractor (c)	Bus (t)
Carrot	Car (p)	Carrot (t)	Pear (c)	Squirrel (u)
Cooker	Boots (u)	Cooker (t)	Crab (p)	Fridge (c)
Cot	Cot (t)	Cake (p)	Chair (c)	Butterfly (u)
Fire-engine	Table (u)	Frog (p)	Fire-engine (t)	Helicopter (c)
Horse	Horse (t)	Fish (c)	Bicycle (u)	Hat (p)
Pig	Pushchair (p)	Chicken (c)	Sandwich (u)	Pig (t)
Strawberry	Cucumber (c)	Boat (u)	Snail (p)	Strawberry (t)
Tomato	Tomato (t)	Coat (u)	Tiger (p)	Peas (c)
Turtle	Bear (c)	Turtle (t)	Chips (u)	TV (p)

Note: t = target, p = phonological distractor, c = taxonomic distractor, u = unrelated distractor.

Table A.8. Experiment 1–Test List 4a. Trial order was randomized by the eye-tracking software.

List D1	*Picture Position*			
	Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Target Word	**Pictures (Picture Role)**			
Bath	Bath (t)	Peas (u)	Sofa (c)	Bear (p)
Butterfly	Butterfly (t)	Bus (p)	Pear (u)	Squirrel (c)
Car	Bicycle (c)	Cow (p)	Car (t)	Chair (u)
Cat	Cooker (p)	Cat (t)	Fire-engine (u)	Penguin (c)
Chips	TV (u)	Chips (t)	Cake (c)	Chicken (p)
Coat	Coat (t)	Boots (c)	Carrot (p)	Horse (u)
Cucumber	Cot (p)	Pig (u)	Tomato (c)	Cucumber (t)
Hat	Bib (c)	Hat (t)	Helicopter (p)	Fish (u)
Sandwich	Crab (u)	Biscuit (c)	Sandwich (t)	Sock (p)
Snail	Pushchair (u)	Bee (c)	Strawberry (p)	Snail (t)
Tiger	Table (p)	Banana (u)	Tiger (t)	Frog (c)
Tractor	Boat (c)	Turtle (p)	Fridge (u)	Tractor (t)

Note: t = target, p = phonological distractor, c = taxonomic distractor, u = unrelated distractor.

Table A.9. Experiment 1–Test List 4b. Trial order was randomized by the eye-tracking software.

List D2	*Picture Position*			
	Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Target Word	**Pictures (Picture Role)**			
Bath	Peas (u)	Bear (p)	Sofa (c)	Bath (t)
Butterfly	Bus (p)	Squirrel (c)	Pear (u)	Butterfly (t)
Car	Cow (p)	Car (t)	Bicycle (c)	Chair (u)
Cat	Penguin (c)	Fire-engine (u)	Cat (t)	Cooker (p)
Chips	TV (u)	Chicken (p)	Chips (t)	Cake (c)
Coat	Boots (c)	Horse (u)	Carrot (p)	Coat (t)
Cucumber	Cucumber (t)	Pig (u)	Cot (p)	Tomato (c)
Hat	Helicopter (p)	Bib (c)	Hat (t)	Fish (u)
Sandwich	Crab (u)	Sandwich (t)	Sock (p)	Biscuit (c)
Snail	Snail (t)	Bee (c)	Pushchair (u)	Strawberry (p)
Tiger	Frog (c)	Tiger (t)	Banana (u)	Table (p)
Tractor	Tractor (t)	Turtle (p)	Boat (c)	Fridge (u)

Note: t = target, p = phonological distractor, c = taxonomic distractor, u = unrelated distractor.

Appendix B

Experiment 2

Table B.1. Experiment 2 stimuli yoke list.

Yoke Set	Target Word	Distractor Pictures			
		Phonological	***Taxonomic***	***Unrelated 1***	***Unrelated 2***
1	Trousers	Train	Hat	Fridge	Bear
	Boat	Bear	Train	Hat	Fridge
	Hoover	Hat	Fridge	Bear	Train
	Frog	Fridge	Bear	Train	Hat
2	Squirrel	Soap	Duck	Blocks	Tomato
	Doll	Duck	Blocks	Tomato	Soap
	Towel	Tomato	Soap	Duck	Blocks
	Banana	Blocks	Tomato	Soap	Duck
3	Boots	Butterfly	Coat	Peas	Tractor
	Tiger	Tractor	Butterfly	Coat	Peas
	Cake	Coat	Peas	Tractor	Butterfly
	Pushchair	Peas	Tractor	Butterfly	Coat
4	Digger	Dress	Bus	Cat	Sandwich
	Cucumber	Cat	Sandwich	Dress	Bus
	Bee	Bus	Cat	Sandwich	Dress
	Sock	Sandwich	Dress	Bus	Cat
5	Bath	Bicycle	Sofa	Carrot	Turtle
	Cow	Carrot	Turtle	Bicycle	Sofa
	Strawberry	Sofa	Carrot	Turtle	Bicycle
	Truck	Turtle	Bicycle	Sofa	Carrot
6	Toast	TV	Pear	Horse	Car
	Helicopter	Horse	Car	TV	Pear
	Cot	Car	TV	Pear	Horse
	Penguin	Pear	Horse	Car	TV

Table B.2. Experiment 2–Test List 1.

List 1			*Picture Position*			
			Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Type**	**Target**	**Pictures (Picture Role)**			
0	Filler	Juice	Juice (t)	Nappy (u1)	Brush (u2)	Keys (u3)
1	Filler	Fire-engine	Grape (u)	Fire-engine (t)	Fish (p)	Aeroplane (c)
	Test	Trousers	Train (p)	Hat (c)	Bear (u2)	Fridge (u1)
	Test	Squirrel	Duck (c)	Soap (p)	Blocks (u1)	Tomato (u2)
	Filler	Chocolate	Icecream (c)	Umbrella (u)	Chocolate (t)	Chicken (p)
	Test	Bath	Bicycle (p)	Carrot (u1)	Sofa (c)	Turtle (u2)
	Test	Toast	Pear (c)	Car (u2)	TV (p)	Horse (u1)
	Filler	Bib	Book (p)	Shoes (c)	Clock (u)	Bib (t)
	Test	Digger	Sandwich (u2)	Dress (p)	Cat (u1)	Bus (c)
	Test	Boots	Peas (u1)	Butterfly (p)	Coat (c)	Tractor (u2)
2	Filler	Monkey	Monkey (t)	Milk (p)	Dog (c)	Telephone (u)
	Test	Boat	Hat (u1)	Bear (p)	Fridge (u2)	Train(c)
	Test	Cow	Sofa (u2)	Turtle (c)	Bicycle (u1)	Carrot (p)
	Filler	Spoon	Ambulance (u)	Spoon (t)	Swing (p)	Glass (c)
	Test	Tiger	Butterfly (c)	Coat (u1)	Tractor (p)	Peas (u2)
	Test	Cucumber	Cat (p)	Bus (u2)	Sandwich (c)	Dress (u1)
	Filler	Teddy	Ball (c)	Flower (u)	Teddy (t)	Table (p)
	Test	Helicopter	TV (u1)	Horse (p)	Pear (u2)	Car (c)
	Test	Doll	Soap (u2)	Blocks (c)	Tomato (u1)	Duck (p)
3	Filler	Pig	Pen (p)	Elephant (c)	Button (u)	Pig (t)
	Test	Strawberry	Turtle (u1)	Bicycle (u2)	Carrot (c)	Sofa (p)
	Test	Bee	Dress (u2)	Cat (c)	Bus (p)	Sandwich (u1)
	Filler	Hand	Hand (t)	Raisins (u1)	Tree (u2)	Window (u3)
	Test	Cake	Tractor (u1)	Peas (c)	Butterfly (u2)	Coat (p)
	Test	Hoover	Fridge (c)	Train (u2)	Hat (p)	Bear (u1)
	Filler	Cup	Watch (u)	Cup (t)	Caterpillar (p)	Fork (c)
	Test	Towel	Tomato (p)	Duck (u1)	Soap (c)	Blocks (u2)
	Test	Cot	Car (p)	TV (c)	Horse (u2)	Pear (u1)
4	Filler	Spade	Watering Can (c)	Door (u)	Spade (t)	Snail (p)
	Test	Pushchair	Coat (u2)	Tractor (c)	Peas (p)	Butterfly (u1)
	Test	Sock	Bus (u1)	Sandwich (p)	Dress (c)	Cat (u2)
	Filler	Bunny	Bag (p)	Lion (c)	Plate (u)	Bunny (t)
	Test	Truck	Carrot (u2)	Sofa (u1)	Turtle (p)	Bicycle (c)
	Test	Frog	Bear (c)	Fridge (p)	Train (u1)	Hat (u2)
	Filler	Slide	Slide (t)	Cooker (u1)	Orange (u2)	Toothbrush (u3)
	Test	Banana	Blocks (p)	Tomato (c)	Duck (u2)	Soap (u1)
	Test	Penguin	Horse (c)	Pear (p)	Car (u1)	TV (u2)

Note: p = phonological distractor, c = taxonomic distractor, u = unrelated distractors, t = target

Table B.3. Experiment 2–Test List 2.

List 2			*Picture Position*			
			Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Type**	**Target**	**Pictures (Picture Role)**			
0	Filler	Juice	Nappy (u1)	Brush (u2)	Keys (u3)	Juice (t)
2	Filler	Monkey	Milk (p)	Dog (c)	Telephone (u)	Monkey (t)
	Test	Boat	Bear (p)	Fridge (u2)	Train(c)	Hat (u1)
	Test	Cow	Turtle (c)	Bicycle (u1)	Carrot (p)	Sofa (u2)
	Filler	Spoon	Spoon (t)	Swing (p)	Glass (c)	Ambulance (u)
	Test	Tiger	Coat (u1)	Tractor (p)	Peas (u2)	Butterfly (c)
	Test	Cucumber	Bus (u2)	Sandwich (c)	Dress (u1)	Cat (p)
	Filler	Teddy	Flower (u)	Teddy (t)	Table (p)	Ball (c)
	Test	Helicopter	Horse (p)	Pear (u2)	Car (c)	TV (u1)
	Test	Doll	Blocks (c)	Tomato (u1)	Duck (p)	Soap (u2)
3	Filler	Pig	Elephant (c)	Button (u)	Pig (t)	Pen (p)
	Test	Strawberry	Bicycle (u2)	Carrot (c)	Sofa (p)	Turtle (u1)
	Test	Bee	Cat (c)	Bus (p)	Sandwich (u1)	Dress (u2)
	Filler	Hand	Raisins (u1)	Tree (u2)	Window (u3)	Hand (t)
	Test	Cake	Peas (c)	Butterfly (u2)	Coat (p)	Tractor (u1)
	Test	Hoover	Train (u2)	Hat (p)	Bear (u1)	Fridge (c)
	Filler	Cup	Cup (t)	Caterpillar (p)	Fork (c)	Watch (u)
	Test	Towel	Duck (u1)	Soap (c)	Blocks (u2)	Tomato (p)
	Test	Cot	TV (c)	Horse (u2)	Pear (u1)	Car (p)
4	Filler	Spade	Door (u)	Spade (t)	Snail (p)	Watering Can (c)
	Test	Pushchair	Tractor (c)	Peas (p)	Butterfly (u1)	Coat (u2)
	Test	Sock	Sandwich (p)	Dress (c)	Cat (u2)	Bus (u1)
	Filler	Bunny	Lion (c)	Plate (u)	Bunny (t)	Bag (p)
	Test	Truck	Sofa (u1)	Turtle (p)	Bicycle (c)	Carrot (u2)
	Test	Frog	Fridge (p)	Train (u1)	Hat (u2)	Bear (c)
	Filler	Slide	Cooker (u1)	Orange (u2)	Toothbrush (u3)	Slide (t)
	Test	Banana	Tomato (c)	Duck (u2)	Soap (u1)	Blocks (p)
	Test	Penguin	Pear (p)	Car (u1)	TV (u2)	Horse (c)
1	Filler	Fire-engine	Fire-engine (t)	Fish (p)	Aeroplane (c)	Grape (u)
	Test	Trousers	Hat (c)	Bear (u2)	Fridge (u1)	Train (p)
	Test	Squirrel	Soap (p)	Blocks (u1)	Tomato (u2)	Duck (c)
	Filler	Chocolate	Umbrella (u)	Chocolate (t)	Chicken (p)	Icecream (c)
	Test	Bath	Carrot (u1)	Sofa (c)	Turtle (u2)	Bicycle (p)
	Test	Toast	Car (u2)	TV (p)	Horse (u1)	Pear (c)
	Filler	Bib	Shoes (c)	Clock (u)	Bib (t)	Book (p)
	Test	Digger	Dress (p)	Cat (u1)	Bus (c)	Sandwich (u2)
	Test	Boots	Butterfly (p)	Coat (c)	Tractor (u2)	Peas (u1)

Note: p = phonological distractor, c = taxonomic distractor, u = unrelated distractors, t = target

Table B.4. Experiment 2–Test List 3.

List 3				*Picture Position*		
			Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Type**	**Target**	**Pictures (Picture Role)**			
0	Filler	Juice	Brush (u2)	Keys (u3)	Juice (t)	Nappy (u1)
3	Filler	Pig	Button (u)	Pig (t)	Pen (p)	Elephant (c)
	Test	Strawberry	Carrot (c)	Sofa (p)	Turtle (u1)	Bicycle (u2)
	Test	Bee	Bus (p)	Sandwich (u1)	Dress (u2)	Cat (c)
	Filler	Hand	Tree (u2)	Window (u3)	Hand (t)	Raisins (u1)
	Test	Cake	Butterfly (u2)	Coat (p)	Tractor (u1)	Peas (c)
	Test	Hoover	Hat (p)	Bear (u1)	Fridge (c)	Train (u2)
	Filler	Cup	Caterpillar (p)	Fork (c)	Watch (u)	Cup (t)
	Test	Towel	Soap (c)	Blocks (u2)	Tomato (p)	Duck (u1)
	Test	Cot	Horse (u2)	Pear (u1)	Car (p)	TV (c)
4	Filler	Spade	Spade (t)	Snail (p)	Watering Can (c)	Door (u)
	Test	Pushchair	Peas (p)	Butterfly (u1)	Coat (u2)	Tractor (c)
	Test	Sock	Dress (c)	Cat (u2)	Bus (u1)	Sandwich (p)
	Filler	Bunny	Plate (u)	Bunny (t)	Bag (p)	Lion (c)
	Test	Truck	Turtle (p)	Bicycle (c)	Carrot (u2)	Sofa (u1)
	Test	Frog	Train (u1)	Hat (u2)	Bear (c)	Fridge (p)
	Filler	Slide	Orange (u2)	Toothbrush (u3)	Slide (t)	Cooker (u1)
	Test	Banana	Duck (u2)	Soap (u1)	Blocks (p)	Tomato (c)
	Test	Penguin	Car (u1)	TV (u2)	Horse (c)	Pear (p)
1	Filler	Fire-engine	Fish (p)	Aeroplane (c)	Grape (u)	Fire-engine (t)
	Test	Trousers	Bear (u2)	Fridge (u1)	Train (p)	Hat (c)
	Test	Squirrel	Blocks (u1)	Tomato (u2)	Duck (c)	Soap (p)
	Filler	Chocolate	Chocolate (t)	Chicken (p)	Icecream (c)	Umbrella (u)
	Test	Bath	Sofa (c)	Turtle (u2)	Bicycle (p)	Carrot (u1)
	Test	Toast	TV (p)	Horse (u1)	Pear (c)	Car (u2)
	Filler	Bib	Clock (u)	Bib (t)	Book (p)	Shoes (c)
	Test	Digger	Cat (u1)	Bus (c)	Sandwich (u2)	Dress (p)
	Test	Boots	Coat (c)	Tractor (u2)	Peas (u1)	Butterfly (p)
2	Filler	Monkey	Dog (c)	Telephone (u)	Monkey (t)	Milk (p)
	Test	Boat	Fridge (u2)	Train(c)	Hat (u1)	Bear (p)
	Test	Cow	Bicycle (u1)	Carrot (p)	Sofa (u2)	Turtle (c)
	Filler	Spoon	Swing (p)	Glass (c)	Ambulance (u)	Spoon (t)
	Test	Tiger	Tractor (p)	Peas (u2)	Butterfly (c)	Coat (u1)
	Test	Cucumber	Sandwich (c)	Dress (u1)	Cat (p)	Bus (u2)
	Filler	Teddy	Teddy (t)	Table (p)	Ball (c)	Flower (u)
	Test	Helicopter	Pear (u2)	Car (c)	TV (u1)	Horse (p)
	Test	Doll	Tomato (u1)	Duck (p)	Soap (u2)	Blocks (c)

Note: p = phonological distractor, c = taxonomic distractor, u = unrelated distractors, t = target

Table B.5. Experiment 2–Test List 4.

List 4			*Picture Position*			
			Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Type**	**Target**	**Pictures (Picture Role)**			
0	Filler	Juice	Keys (u3)	Juice (t)	Nappy (u1)	Brush (u2)
4	Filler	Spade	Snail (p)	Watering Can (c)	Door (u)	Spade (t)
	Test	Pushchair	Butterfly (u1)	Coat (u2)	Tractor (c)	Peas (p)
	Test	Sock	Cat (u2)	Bus (u1)	Sandwich (p)	Dress (c)
	Filler	Bunny	Bunny (t)	Bag (p)	Lion (c)	Plate (u)
	Test	Truck	Bicycle (c)	Carrot (u2)	Sofa (u1)	Turtle (p)
	Test	Frog	Hat (u2)	Bear (c)	Fridge (p)	Train (u1)
	Filler	Slide	Toothbrush (u3)	Slide (t)	Cooker (u1)	Orange (u2)
	Test	Banana	Soap (u1)	Blocks (p)	Tomato (c)	Duck (u2)
	Test	Penguin	TV (u2)	Horse (c)	Pear (p)	Car (u1)
1	Filler	Fire-engine	Aeroplane (c)	Grape (u)	Fire-engine (t)	Fish (p)
	Test	Trousers	Fridge (u1)	Train (p)	Hat (c)	Bear (u2)
	Test	Squirrel	Tomato (u2)	Duck (c)	Soap (p)	Blocks (u1)
	Filler	Chocolate	Chicken (p)	Icecream (c)	Umbrella (u)	Chocolate (t)
	Test	Bath	Turtle (u2)	Bicycle (p)	Carrot (u1)	Sofa (c)
	Test	Toast	Horse (u1)	Pear (c)	Car (u2)	TV (p)
	Filler	Bib	Bib (t)	Book (p)	Shoes (c)	Clock (u)
	Test	Digger	Bus (c)	Sandwich (u2)	Dress (p)	Cat (u1)
	Test	Boots	Tractor (u2)	Peas (u1)	Butterfly (p)	Coat (c)
2	Filler	Monkey	Telephone (u)	Monkey (t)	Milk (p)	Dog (c)
	Test	Boat	Train(c)	Hat (u1)	Bear (p)	Fridge (u2)
	Test	Cow	Carrot (p)	Sofa (u2)	Turtle (c)	Bicycle (u1)
	Filler	Spoon	Glass (c)	Ambulance (u)	Spoon (t)	Swing (p)
	Test	Tiger	Peas (u2)	Butterfly (c)	Coat (u1)	Tractor (p)
	Test	Cucumber	Dress (u1)	Cat (p)	Bus (u2)	Sandwich (c)
	Filler	Teddy	Table (p)	Ball (c)	Flower (u)	Teddy (t)
	Test	Helicopter	Car (c)	TV (u1)	Horse (p)	Pear (u2)
	Test	Doll	Duck (p)	Soap (u2)	Blocks (c)	Tomato (u1)
3	Filler	Pig	Pig (t)	Pen (p)	Elephant (c)	Button (u)
	Test	Strawberry	Sofa (p)	Turtle (u1)	Bicycle (u2)	Carrot (c)
	Test	Bee	Sandwich (u1)	Dress (u2)	Cat (c)	Bus (p)
	Filler	Hand	Window (u3)	Hand (t)	Raisins (u1)	Tree (u2)
	Test	Cake	Coat (p)	Tractor (u1)	Peas (c)	Butterfly (u2)
	Test	Hoover	Bear (u1)	Fridge (c)	Train (u2)	Hat (p)
	Filler	Cup	Fork (c)	Watch (u)	Cup (t)	Caterpillar (p)
	Test	Towel	Blocks (u2)	Tomato (p)	Duck (u1)	Soap (c)
	Test	Cot	Pear (u1)	Car (p)	TV (c)	Horse (u2)

Note: p = phonological distractor, c = taxonomic distractor, u = unrelated distractors, t = target

Appendix C

Experiment 3

Table C.1. Experiment 3 stimuli yoke list.

Yoke Set	Target Word	Distractor Pictures			
		Phonological	*Thematic*	*Unrelated 1*	*Unrelated 2*
1	Sky	Spade	Rocket	Windows	Carrot
	Rabbit	Rocket	Carrot	Spade	Windows
	Curtains	Carrot	Windows	Rocket	Spade
	Watering Can	Windows	Spade	Carrot	Rocket
2	Hair	House	Brush	Flower	Camera
	Key	Camera	House	Brush	Flower
	Butterfly	Brush	Flower	Camera	House
	Photo	Flower	Camera	House	Brush
3	Banana	Bin	Monkey	Cup	Road
	Milk	Monkey	Cup	Road	Bin
	Rubbish	Road	Bin	Monkey	Cup
	Car	Cup	Road	Bin	Monkey
4	Party	Papers	Balloon	Tree	Spoon
	Book	Balloon	Papers	Spoon	Tree
	Squirrel	Spoon	Tree	Papers	Balloon
	Table	Tree	Spoon	Balloon	Papers
5	Shoe	Sheep	Foot	Bowl	Soap
	Farm	Foot	Sheep	Soap	Bowl
	Cereal	Soap	Bowl	Foot	Sheep
	Bath	Bowl	Soap	Sheep	Foot
6	Baby	Button	Pushchair	Cushions	Swing
	Park	Pushchair	Swing	Button	Cushions
	Sofa	Swing	Cushions	Pushchair	Button
	Coat	Cushions	Button	Swing	Pushchair

Table C.2. Experiment 3–Test List 1.

List 1			*Picture Position*			
			Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Type**	**Target**	**Pictures (Picture Role)**			
0	Filler	grape	grape (t)	highchair (u1)	train (u2)	fish (u3)
1	Filler	sock	pear (u3)	sock (t)	tV (u1)	bicycle (u2)
	Test	sky	spade (p)	rocket (a)	windows (u1)	carrot (u2)
	Test	butterfly	flower (a)	camera (u1)	house (u2)	brush (p)
	Filler	chicken	fork (u2)	bus (u3)	chicken (t)	nappy (u1)
	Test	rubbish	cup (u2)	road(p)	bin (a)	monkey (u1)
	Test	book	spoon (u1)	paper (a)	balloons (p)	tree (u2)
	Filler	apple	hat (u1)	duck (u2)	apple (t)	blocks (u3)
	Test	bath	foot (u2)	bowl (p)	soap (a)	sheep (u1)
	Test	park	swing (a)	button (u1)	pushchair (p)	cushions (u2)
2	Filler	boat	boat (t)	tomato (u1)	lion (u2)	doll (u3)
	Test	rabbit	carrot (a)	spade (u1)	rocket (p)	windows (u2)
	Test	coat	pushchair (u2)	cushions (p)	swing (u1)	button (a)
	Filler	towel	Cat(u3)	Towel(t)	Boots(u1)	Raisins(u2)
	Test	shoe	sheep (p)	foot (a)	bowl (u1)	soap (u2)
	Test	photo	brush (u2)	flower (p)	camera (a)	house (u1)
	Filler	potty	fridge (u2)	hand (u3)	bee (u1)	potty (t)
	Test	car	monkey (u2)	cup (p)	road (a)	bin (u1)
	Test	squirrel	tree (a)	spoon (p)	paper (u1)	balloons (u2)
3	Filler	sandwich	bed (u1)	dress (u2)	aeroplane (u3)	sandwich (t)
	Test	hair	house (p)	brush (a)	flower (u1)	camera (u2)
	Test	banana	bin (p)	monkey (a)	cup (u1)	road (u2)
	Filler	bag	bag (t)	tiger (u1)	cake (u2)	helicopter (u3)
	Test	farm	soap (u1)	sheep (a)	foot (p)	bowl (u2)
	Test	curtain	windows (a)	carrot (p)	spade (u2)	rocket (u1)
	Filler	fire engine	hoover (u3)	fire engine (t)	teddy (u1)	cucumber (u2)
	Test	table	balloons (u1)	tree (p)	spoon (a)	paper (u2)
	Test	baby	button (p)	pushchair (a)	cushions (u1)	swing (u2)
4	Filler	strawberry	digger (u2)	telephone (u3)	strawberry (t)	penguin (u1)
	Test	party	paper (p)	balloons (a)	tree (u1)	spoon (u2)
	Test	cereal	bowl (a)	soap (p)	sheep (u2)	foot (u1)
	Filler	dog	tractor (u1)	clock (u2)	peas (u3)	dog (t)
	Test	milk	road (u1)	bin (u2)	monkey (p)	cup (a)
	Test	sofa	cushions (a)	swing (p)	button (u2)	pushchair (u1)
	Filler	horse	horse (t)	bib (u1)	pen (u2)	icecream (u3)
	Test	key	camera (p)	house (a)	brush (u1)	flower (u2)
	Test	watering can	rocket (u2)	windows (p)	carrot (u1)	spade (a)

Note: p = phonological distractor, a = thematic distractor, u = unrelated distractors, t = target

Table C.3. Experiment 3–Test List 2.

List 2			Picture Position			
			Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Type**	**Target**	**Pictures (Picture Role)**			
0	Filler	grape	highchair (u1)	train (u2)	fish (u3)	grape (t)
	Filler	boat	tomato (u1)	lion (u2)	doll (u3)	boat (t)
	Test	rabbit	spade (u1)	rocket (p)	windows (u2)	carrot (a)
	Test	coat	cushions (p)	swing (u1)	button (a)	pushchair (u2)
	Filler	towel	Towel(t)	Boots(u1)	Raisins(u2)	Cat(u3)
2	Test	shoe	foot (a)	bowl (u1)	soap (u2)	sheep (p)
	Test	photo	flower (p)	camera (a)	house (u1)	brush (u2)
	Filler	potty	hand (u3)	bee (u1)	potty (t)	fridge (u2)
	Test	car	cup (p)	road (a)	bin (u1)	monkey (u2)
	Test	squirrel	spoon (p)	paper (u1)	balloons (u2)	tree (a)
	Filler	sandwich	dress (u2)	aeroplane (u3)	sandwich (t)	bed (u1)
	Test	hair	brush (a)	flower (u1)	camera (u2)	house (p)
	Test	banana	monkey (a)	cup (u1)	road (u2)	bin (p)
	Filler	bag	tiger (u1)	cake (u2)	helicopter (u3)	bag (t)
3	Test	farm	sheep (a)	foot (p)	bowl (u2)	soap (u1)
	Test	curtain	carrot (p)	spade (u2)	rocket (u1)	windows (a)
	Filler	fire engine	fire engine (t)	teddy (u1)	cucumber (u2)	hoover (u3)
	Test	table	tree (p)	spoon (a)	paper (u2)	balloons (u1)
	Test	baby	pushchair (a)	cushions (u1)	swing (u2)	button (p)
	Filler	strawberry	telephone (u3)	strawberry (t)	penguin (u1)	digger (u2)
	Test	party	balloons (a)	tree (u1)	spoon (u2)	paper (p)
	Test	cereal	soap (p)	sheep (u2)	foot (u1)	bowl (a)
	Filler	dog	clock (u2)	peas (u3)	dog (t)	tractor (u1)
4	Test	milk	bin (u2)	monkey (p)	cup (a)	road (u1)
	Test	sofa	swing (p)	button (u2)	pushchair (u1)	cushions (a)
	Filler	horse	bib (u1)	pen (u2)	icecream (u3)	horse (t)
	Test	key	house (a)	brush (u1)	flower (u2)	camera (p)
	Test	watering can	windows (p)	carrot (u1)	spade (a)	rocket (u2)
	Filler	sock	sock (t)	tV (u1)	bicycle (u2)	pear (u3)
	Test	sky	rocket (a)	windows (u1)	carrot (u2)	spade (p)
	Test	butterfly	camera (u1)	house (u2)	brush (p)	flower (a)
	Filler	chicken	bus (u3)	chicken (t)	nappy (u1)	fork (u2)
1	Test	rubbish	road(p)	bin (a)	monkey (u1)	cup (u2)
	Test	book	paper (a)	balloons (p)	tree (u2)	spoon (u1)
	Filler	apple	duck (u2)	apple (t)	blocks (u3)	hat (u1)
	Test	bath	bowl (p)	soap (a)	sheep (u1)	foot (u2)
	Test	park	button (u1)	pushchair (p)	cushions (u2)	swing (a)

Note: p = phonological distractor, a = thematic distractor, u = unrelated distractors, t = target

Table C.4. Experiment 3–Test List 3.

List 3			*Picture Position*			
			Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Type**	**Target**	**Pictures (Picture Role)**			
0	Filler	grape	train (u2)	fish (u3)	grape (t)	highchair (u1)
3	Filler	sandwich	aeroplane (u3)	sandwich (t)	bed (u1)	dress (u2)
	Test	hair	flower (u1)	camera (u2)	house (p)	brush (a)
	Test	banana	cup (u1)	road (u2)	bin (p)	monkey (a)
	Filler	bag	cake (u2)	helicopter (u3)	bag (t)	tiger (u1)
	Test	farm	foot (p)	bowl (u2)	soap (u1)	sheep (a)
	Test	curtain	spade (u2)	rocket (u1)	windows (a)	carrot (p)
	Filler	fire engine	teddy (u1)	cucumber (u2)	hoover (u3)	fire engine (t)
	Test	table	spoon (a)	paper (u2)	balloons (u1)	tree (p)
	Test	baby	cushions (u1)	swing (u2)	button (p)	pushchair (a)
4	Filler	strawberry	strawberry (t)	penguin (u1)	digger (u2)	telephone (u3)
	Test	party	tree (u1)	spoon (u2)	paper (p)	balloons (a)
	Test	cereal	sheep (u2)	foot (u1)	bowl (a)	soap (p)
	Filler	dog	peas (u3)	dog (t)	tractor (u1)	clock (u2)
	Test	milk	monkey (p)	cup (a)	road (u1)	bin (u2)
	Test	sofa	button (u2)	pushchair (u1)	cushions (a)	swing (p)
	Filler	horse	pen (u2)	icecream (u3)	horse (t)	bib (u1)
	Test	key	brush (u1)	flower (u2)	camera (p)	house (a)
	Test	watering can	carrot (u1)	spade (a)	rocket (u2)	windows (p)
1	Filler	sock	tV (u1)	bicycle (u2)	pear (u3)	sock (t)
	Test	sky	windows (u1)	carrot (u2)	spade (p)	rocket (a)
	Test	butterfly	house (u2)	brush (p)	flower (a)	camera (u1)
	Filler	chicken	chicken (t)	nappy (u1)	fork (u2)	bus (u3)
	Test	rubbish	bin (a)	monkey (u1)	cup (u2)	road(p)
	Test	book	balloons (p)	tree (u2)	spoon (u1)	paper (a)
	Filler	apple	apple (t)	blocks (u3)	hat (u1)	duck (u2)
	Test	bath	soap (a)	sheep (u1)	foot (u2)	bowl (p)
	Test	park	pushchair (p)	cushions (u2)	swing (a)	button (u1)
2	Filler	boat	lion (u2)	doll (u3)	boat (t)	tomato (u1)
	Test	rabbit	rocket (p)	windows (u2)	carrot (a)	spade (u1)
	Test	coat	swing (u1)	button (a)	pushchair (u2)	cushions (p)
	Filler	towel	Boots(u1)	Raisins(u2)	Cat(u3)	Towel(t)
	Test	shoe	bowl (u1)	soap (u2)	sheep (p)	foot (a)
	Test	photo	camera (a)	house (u1)	brush (u2)	flower (p)
	Filler	potty	bee (u1)	potty (t)	fridge (u2)	hand (u3)
	Test	car	road (a)	bin (u1)	monkey (u2)	cup (p)
	Test	squirrel	paper (u1)	balloons (u2)	tree (a)	spoon (p)

Note: p = phonological distractor, a = thematic distractor, u = unrelated distractors, t = target

Table C.5. Experiment 3–Test List 4.

List 4			*Picture Position*			
			Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Type**	**Target**	**Pictures (Picture Role)**			
0	Filler	grape	fish (u3)	grape (t)	highchair (u1)	train (u2)
4	Filler	strawberry	penguin (u1)	digger (u2)	telephone (u3)	strawberry (t)
	Test	party	spoon (u2)	paper (p)	balloons (a)	tree (u1)
	Test	cereal	foot (u1)	bowl (a)	soap (p)	sheep (u2)
	Filler	dog	dog (t)	tractor (u1)	clock (u2)	peas (u3)
	Test	milk	cup (a)	road (u1)	bin (u2)	monkey (p)
	Test	sofa	pushchair (u1)	cushions (a)	swing (p)	button (u2)
	Filler	horse	icecream (u3)	horse (t)	bib (u1)	pen (u2)
	Test	key	flower (u2)	camera (p)	house (a)	brush (u1)
	Test	watering can	spade (a)	rocket (u2)	windows (p)	carrot (u1)
1	Filler	sock	bicycle (u2)	pear (u3)	sock (t)	tV (u1)
	Test	sky	carrot (u2)	spade (p)	rocket (a)	windows (u1)
	Test	butterfly	brush (p)	flower (a)	camera (u1)	house (u2)
	Filler	chicken	nappy (u1)	fork (u2)	bus (u3)	chicken (t)
	Test	rubbish	monkey (u1)	cup (u2)	road(p)	bin (a)
	Test	book	tree (u2)	spoon (u1)	paper (a)	balloons (p)
	Filler	apple	blocks (u3)	hat (u1)	duck (u2)	apple (t)
	Test	bath	sheep (u1)	foot (u2)	bowl (p)	soap (a)
	Test	park	cushions (u2)	swing (a)	button (u1)	pushchair (p)
2	Filler	boat	doll (u3)	boat (t)	tomato (u1)	lion (u2)
	Test	rabbit	windows (u2)	carrot (a)	spade (u1)	rocket (p)
	Test	coat	button (a)	pushchair (u2)	cushions (p)	swing (u1)
	Filler	towel	Raisins(u2)	Cat(u3)	Towel(t)	Boots(u1)
	Test	shoe	soap (u2)	sheep (p)	foot (a)	bowl (u1)
	Test	photo	house (u1)	brush (u2)	flower (p)	camera (a)
	Filler	potty	potty (t)	fridge (u2)	hand (u3)	bee (u1)
	Test	car	bin (u1)	monkey (u2)	cup (p)	road (a)
	Test	squirrel	balloons (u2)	tree (a)	spoon (p)	paper (u1)
3	Filler	sandwich	sandwich (t)	bed (u1)	dress (u2)	aeroplane (u3)
	Test	hair	camera (u2)	house (p)	brush (a)	flower (u1)
	Test	banana	road (u2)	bin (p)	monkey (a)	cup (u1)
	Filler	bag	helicopter (u3)	bag (t)	tiger (u1)	cake (u2)
	Test	farm	bowl (u2)	soap (u1)	sheep (a)	foot (p)
	Test	curtain	rocket (u1)	windows (a)	carrot (p)	spade (u2)
	Filler	fire engine	cucumber (u2)	hoover (u3)	fire engine (t)	teddy (u1)
	Test	table	paper (u2)	balloons (u1)	tree (p)	spoon (a)
	Test	baby	swing (u2)	button (p)	pushchair (a)	cushions (u1)

Note: p = phonological distractor, a = thematic distractor, u = unrelated distractors, t = target

Appendix D

Experiment 4

Table D.1. Experiment 4 stimuli yoke list.

Test Trial	*Target*	*Cohort*	*Rhyme*	*Distrcator 1*	*Distractor 2*
1	Pear	Pen	Chair	Fish	Swing
2	Boat	Bowl	Coat	Door	Tree
3	Bag	Ball	Flag	Horse	Juice
4	Duck	Dummy	Truck	Sofa	Shoes
5	Head	Helicopter	Bed	Cake	Dress
6	Wall	Watch	Doll	Strawberry	Towel
7	Cat	Carrot	Hat	Flower	Blocks
8	Beans	Bee	Jeans	Slide	Car

Table D.2. Experiment 4–Test List 1.

List 1				*Picture Position*			
				Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Trial**	**Type**	**Target**	**Pictures (Picture Role)**			
0	F1	Filler	Cup	Cup (t)	Pig (u1)	Train (u2)	Soap (u3)
	F2	Filler	Digger	TV (u3)	Digger (t)	Bunny (u1)	Cheese (u2)
1	F3	Filler	Bath	Orange (u2)	Spade (u3)	Bath (t)	Cow (u1)
	T1	Test	Pear	Pen (c)	Chair (r)	Fish (u1)	Swing (u2)
	T2	Test	Boat	Tree (u2)	Bowl (c)	Coat (r)	Door (u1)
2	F4	Filler	Table	Chicken (u1)	Bicycle (u2)	Sandwich (u3)	Table (t)
	T3	Test	Bag	Horse (u1)	Juice (u2)	Ball (c)	Flag (r)
	T4	Test	Duck	Truck (r)	Sofa (u1)	Shoes (u2)	Dummy (c)
3	F5	Filler	Keys	Keys (t)	Tiger (u1)	Pasta (u2)	Aeroplane (u3)
	T5	Test	Head	Helicopter (c)	Bed (r)	Cake (u1)	Dress (u2)
	T6	Test	Wall	Towel (u2)	Watch (c)	Doll (r)	Strawberry (u1)
4	F6	Filler	Fork	Window (u3)	Fork (t)	Nappy (u1)	Bus (u2)
	T7	Test	Cat	Flower (u1)	Blocks (u2)	Carrot (c)	Hat (r)
	T8	Test	Beans	Jeans (r)	Slide (u1)	Car (u2)	Bee (c)

Note: c = cohort distractor, r = rhyme distractor, u = unrelated distractors

Table D.3. Experiment 4–Test List 2.

List 2				*Picture Position*			
				Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Trial**	**Type**	**Target**	**Pictures (Picture Role)**			
0	F1	Filler	Cup	Pig (u1)	Train (u2)	Soap (u3)	Cup (t)
	F2	Filler	Digger	Digger (t)	Bunny (u1)	Cheese (u2)	TV (u3)
2	F4	Filler	Table	Bicycle (u2)	Sandwich (u3)	Table (t)	Chicken (u1)
	T3	Test	Bag	Juice (u2)	Ball (c)	Flag (r)	Horse (u1)
	T4	Test	Duck	Sofa (u1)	Shoes (u2)	Dummy (c)	Truck (r)
3	F5	Filler	Keys	Tiger (u1)	Pasta (u2)	Aeroplane (u3)	Keys (t)
	T5	Test	Head	Bed (r)	Cake (u1)	Dress (u2)	Helicopter (c)
	T6	Test	Wall	Watch (c)	Doll (r)	Strawberry (u1)	Towel (u2)
4	F6	Filler	Fork	Fork (t)	Nappy (u1)	Bus (u2)	Window (u3)
	T7	Test	Cat	Blocks (u2)	Carrot (c)	Hat (r)	Flower (u1)
	T8	Test	Beans	Slide (u1)	Car (u2)	Bee (c)	Jeans (r)
1	F3	Filler	Bath	Spade (u3)	Bath (t)	Cow (u1)	Orange (u2)
	T1	Test	Pear	Chair (r)	Fish (u1)	Swing (u2)	Pen (c)
	T2	Test	Boat	Bowl (c)	Coat (r)	Door (u1)	Tree (u2)

Note: c = cohort distractor, r = rhyme distractor, u = unrelated distractors

Table D.4. Experiment 4–Test List 3.

List 3				*Picture Position*			
				Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Trial**	**Type**	**Target**	**Pictures (Picture Role)**			
0	F1	Filler	Cup	Train (u2)	Soap (u3)	Cup (t)	Pig (u1)
	F2	Filler	Digger	Bunny (u1)	Cheese (u2)	TV (u3)	Digger (t)
3	F5	Filler	Keys	Pasta (u2)	Aeroplane (u3)	Keys (t)	Tiger (u1)
	T5	Test	Head	Cake (u1)	Dress (u2)	Helicopter (c)	Bed (r)
	T6	Test	Wall	Doll (r)	Strawberry (u1)	Towel (u2)	Watch (c)
4	F6	Filler	Fork	Nappy (u1)	Bus (u2)	Window (u3)	Fork (t)
	T7	Test	Cat	Carrot (c)	Hat (r)	Flower (u1)	Blocks (u2)
	T8	Test	Beans	Car (u2)	Bee (c)	Jeans (r)	Slide (u1)
1	F3	Filler	Bath	Bath (t)	Cow (u1)	Orange (u2)	Spade (u3)
	T1	Test	Pear	Fish (u1)	Swing (u2)	Pen (c)	Chair (r)
	T2	Test	Boat	Coat (r)	Door (u1)	Tree (u2)	Bowl (c)
2	F4	Filler	Table	Sandwich (u3)	Table (t)	Chicken (u1)	Bicycle (u2)
	T3	Test	Bag	Ball (c)	Flag (r)	Horse (u1)	Juice (u2)
	T4	Test	Duck	Shoes (u2)	Dummy (c)	Truck (r)	Sofa (u1)

Note: c = cohort distractor, r = rhyme distractor, u = unrelated distractors

Table D.5. Experiment 4–Test List 4.

List 4				*Picture Position*			
				Upper Left	*Upper Right*	*Lower Left*	*Lower Right*
Block	**Trial**	**Type**	**Target**	**Pictures (Picture Role)**			
0	F1	Filler	Cup	Soap (u3)	Cup (t)	Pig (u1)	Train (u2)
	F2	Filler	Digger	Cheese (u2)	TV (u3)	Digger (t)	Bunny (u1)
4	F6	Filler	Fork	Bus (u2)	Window (u3)	Fork (t)	Nappy (u1)
	T7	Test	Cat	Hat (r)	Flower (u1)	Blocks (u2)	Carrot (c)
	T8	Test	Beans	Bee (c)	Jeans (r)	Slide (u1)	Car (u2)
1	F3	Filler	Bath	Cow (u1)	Orange (u2)	Spade (u3)	Bath (t)
	T1	Test	Pear	Swing (u2)	Pen (c)	Chair (r)	Fish (u1)
	T2	Test	Boat	Door (u1)	Tree (u2)	Bowl (c)	Coat (r)
2	F4	Filler	Table	Table (t)	Chicken (u1)	Bicycle (u2)	Sandwich (u3)
	T3	Test	Bag	Flag (r)	Horse (u1)	Juice (u2)	Ball (c)
	T4	Test	Duck	Dummy (c)	Truck (r)	Sofa (u1)	Shoes (u2)
3	F5	Filler	Keys	Aeroplane (u3)	Keys (t)	Tiger (u1)	Pasta (u2)
	T5	Test	Head	Dress (u2)	Helicopter (c)	Bed (r)	Cake (u1)
	T6	Test	Wall	Strawberry (u1)	Towel (u2)	Watch (c)	Doll (r)

Note: c = cohort distractor, r = rhyme distractor, u = unrelated distractors

Table D.6. Experiment 4: Growth Curve Analysis by Receptive Vocabulary. The unrelated distractor and participants with a smaller receptive vocabulary were treated as baseline in the model, relative parameters were estimated for the cohort distractor, rhyme distractor and participants with a larger receptive vocabulary.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Cohort	Intercept	0.30(0.03)	8.81	<.001***
	Linear	0.21(0.17)	1.21	.228
	Quadratic	0.45(0.17)	2.56	.0106*
	Cubic	-0.22(0.17)	-1.28	.2016
Rhyme	Intercept	0.15(0.03)	4.39	<.001***
	Linear	0.81(0.18)	4.58	<.001***
	Quadratic	0.15(0.18)	0.83	.4063
	Cubic	-0.53(0.18)	-2.93	.0034**
Receptive Vocabulary	Intercept	0.11(0.09)	1.29	.2046
	Linear	0.04(0.26)	0.15	.8818
	Quadratic	-0.31(0.24)	-1.29	.1969
	Cubic	0.29(0.24)	1.18	.2389
Cohort*Receptive Vocabulary	Intercept	-0.05(0.07)	-0.73	.4677
	Linear	-0.61(0.34)	-1.80	.0715
	Quadratic	0.20(0.35)	0.58	.5586
	Cubic	-0.26(0.35)	-0.73	.4641
Rhyme*Receptive Vocabulary	Intercept	0.07(0.07)	0.99	.3232
	Linear	0.85(0.36)	2.34	.0191*
	Quadratic	1.31(0.36)	3.62	<.001***
	Cubic	-0.69(0.36)	-1.86	.0633

$***p<.001, **p<.01, *p<.05$

Table D.7. Experiment 4: Growth Curve Analysis by Expressive Vocabulary. The unrelated distractor and participants with a smaller expressive vocabulary were treated as baseline in the model, relative parameters were estimated for the cohort distractor, rhyme distractor and participants with a larger expressive vocabulary.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Cohort	Intercept	0.30(0.03)	8.55	<.001***
	Linear	0.20(0.18)	1.15	.2515
	Quadratic	0.52(0.18)	2.88	.004**
	Cubic	-0.33(0.18)	-1.80	.0717
Rhyme	Intercept	0.16(0.04)	4.48	<.001***
	Linear	0.91(0.18)	5.06	<.001***
	Quadratic	0.39(0.18)	2.14	.0323*
	Cubic	-0.65(0.18)	-3.50	<.001***
Expressive Vocabulary	Intercept	0.07(0.36)	0.20	.8458
	Linear	-0.55(1.01)	-0.55	.5836
	Quadratic	-2.44(0.96)	-2.55	.011*
	Cubic	1.59(0.96)	1.66	.0965
Cohort*Expressive Vocabulary	Intercept	-0.02(0.27)	-0.08	.9328
	Linear	016(1.35)	0.12	.9054
	Quadratic	2.00(1.38)	1.44	.1492
	Cubic	-3.09(1.39)	-2.22	.0267*
Rhyme*Expressive Vocabulary	Intercept	010(0.28)	0.35	.7231
	Linear	1.88(1.43)	1.31	.1908
	Quadratic	6.39(1.44)	4.44	<.001***
	Cubic	-3.09(1.39)	-2.22	.0267*

$***p<.001, **p<.01, *p<.05$

Appendix E

Experiment 5

Table E.1. Experiment 5 stimuli list.

Word Pairs		
1	cow	train
2	raisins	windows
3	toast	flower
4	ball	shoes
5	chicken	boat
6	table	bag
7	dog	bus
8	door	toothbrush
9	sock	bath
10	bowl	telephone
11	cat	aeroplane
12	cake	sofa
13	apple	boots
14	swing	brush
15	bird	pushchair
16	nappy	banana
17	cup	chair
18	duck	car
19	coat	bed
20	fish	truck
21	biscuit	trousers
22	TV	strawberry
23	keys	grape
24	elephant	bicycle
Novel 1	stairs	arm
Novel 2	foot	balloon
Novel 3	spoon	tree
Novel 4	book	lion
Novel 5	sheep	star
Novel 6	hand	pig
Novel 7	frog	ear
Novel 8	slide	milk

Table E.2. Experiment 5–Test List 1a.

A1	Condition	*Left*	**Prime**	*Right*	*Left*	**Probe**	*Right*
1	B	cow		**train**	**stairs**		arm
2	A	**raisins**		windows	**foot**		balloon
3	F	toast		**flower**	**toast**		flower
4	D	**ball**		shoes	shoes		**ball**
5	C	chicken		**boat**	chicken		**boat**
6	E	**table**		bag	**bag**		table
7	E	dog		**bus**	bus		**dog**
8	C	**door**		toothbrush	**door**		toothbrush
9	D	sock		**bath**	**bath**		sock
10	F	**bowl**		telephone	bowl		**telephone**
11	A	cat		**aeroplane**	spoon		**tree**
12	B	**cake**		sofa	book		**lion**
13	B	apple		**boots**	**sheep**		star
14	A	**swing**		brush	**hand**		pig
15	F	bird		**pushchair**	**bird**		pushchair
16	D	**nappy**		banana	banana		**nappy**
17	C	cup		**chair**	cup		**chair**
18	E	**duck**		car	**car**		duck
19	E	coat		**bed**	bed		**coat**
20	C	**fish**		truck	**fish**		truck
21	D	biscuit		**trousers**	**trousers**		biscuit
22	F	**TV**		strawberry	TV		**strawberry**
23	A	keys		**grape**	frog		**ear**
24	B	**elephant**		bicycle	slide		**milk**

Note: Target = bold and underline

Table E.3. Experiment 5–Test List 1b.

A2	Condition	Prime *Left*		Prime *Right*	Probe *Left*		Probe *Right*
1	B	**apple**		boots	sheep		**star**
2	A	swing		**brush**	hand		**pig**
3	F	**bird**		pushchair	bird		**pushchair**
4	D	nappy		**banana**	**banana**		nappy
5	C	**cup**		chair	**cup**		chair
6	E	duck		**car**	car		**duck**
7	E	**coat**		bed	**bed**		coat
8	C	fish		**truck**	fish		**truck**
9	D	**biscuit**		trousers	trousers		**biscuit**
10	F	TV		**strawberry**	**TV**		strawberry
11	A	**keys**		grape	**frog**		ear
12	B	elephant		**bicycle**	**slide**		milk
13	B	**cow**		train	stairs		**arm**
14	A	raisins		**windows**	foot		**balloon**
15	F	**toast**		flower	toast		**flower**
16	D	ball		**shoes**	**shoes**		ball
17	C	**chicken**		boat	**chicken**		boat
18	E	table		**bag**	bag		**table**
19	E	**dog**		bus	**bus**		dog
20	C	door		**toothbrush**	door		**toothbrush**
21	D	**sock**		bath	bath		**sock**
22	F	bowl		**telephone**	**bowl**		telephone
23	A	**cat**		aeroplane	**spoon**		tree
24	B	cake		**sofa**	**book**		lion

Note: Target = bold font and underline

Table E.4. Experiment 5–Test List 2a.

B1	Condition	*Left*	Prime	*Right*	*Left*	Probe	*Right*
1	A	cow		**train**	foot		**balloon**
2	F	**raisins**		windows	raisins		**windows**
3	D	toast		**flower**	**flower**		toast
4	C	**ball**		shoes	**ball**		shoes
5	E	chicken		**boat**	boat		**chicken**
6	B	**table**		bag	hand		**pig**
7	B	dog		**bus**	**spoon**		tree
8	E	**door**		toothbrush	**toothbrush**		door
9	C	sock		**bath**	sock		**bath**
10	D	**bowl**		telephone	telephone		**bowl**
11	F	cat		**aeroplane**	**cat**		aeroplane
12	A	**cake**		sofa	**book**		lion
13	A	apple		**boots**	sheep		**star**
14	F	**swing**		brush	swing		**brush**
15	D	bird		**pushchair**	**pushchair**		bird
16	C	**nappy**		banana	**nappy**		banana
17	E	cup		**chair**	chair		**cup**
18	B	**duck**		car	stairs		**arm**
19	B	coat		**bed**	**frog**		ear
20	E	**fish**		truck	**truck**		fish
21	C	biscuit		**trousers**	biscuit		**trousers**
22	D	**TV**		strawberry	strawberry		**TV**
23	F	keys		**grape**	**keys**		grape
24	A	**elephant**		bicycle	**slide**		milk

Note: Target = bold font and underline

Table E.5. Experiment 5–Test List 2b.

B2	Condition	*Left*	**Prime**	*Right*	*Left*	**Probe**	*Right*
1	A	**apple**		boots	**sheep**		star
2	F	swing		**brush**	**swing**		brush
3	D	**bird**		pushchair	pushchair		**bird**
4	C	nappy		**banana**	nappy		**banana**
5	E	**cup**		chair	**chair**		cup
6	B	duck		**car**	**stairs**		arm
7	B	**coat**		bed	frog		**ear**
8	E	fish		**truck**	truck		**fish**
9	C	**biscuit**		trousers	**biscuit**		trousers
10	D	TV		**strawberry**	**strawberry**		TV
11	F	**keys**		grape	keys		**grape**
12	A	elephant		**bicycle**	slide		**milk**
13	A	**cow**		train	**foot**		balloon
14	F	raisins		**windows**	**raisins**		windows
15	D	**toast**		flower	flower		**toast**
16	C	ball		**shoes**	ball		**shoes**
17	E	**chicken**		boat	**boat**		chicken
18	B	table		**bag**	**hand**		pig
19	B	**dog**		bus	spoon		**tree**
20	E	door		**toothbrush**	toothbrush		**door**
21	C	**sock**		bath	**sock**		bath
22	D	bowl		**telephone**	**telephone**		bowl
23	F	**cat**		aeroplane	cat		**aeroplane**
24	A	cake		**sofa**	book		**lion**

Note: Target = bold font and underline

Table E.6. Experiment 5–Test List 3a.

		Prime		Probe	
C1	Condition	*Left*	*Right*	*Left*	*Right*
1	F	cow	**train**	**cow**	train
2	D	**raisins**	windows	windows	**raisins**
3	C	toast	**flower**	toast	**flower**
4	E	**ball**	shoes	**shoes**	ball
5	B	chicken	**boat**	**stairs**	arm
6	A	**table**	bag	**hand**	pig
7	A	dog	**bus**	spoon	**tree**
8	B	**door**	toothbrush	book	**lion**
9	E	sock	**bath**	bath	**sock**
10	C	**bowl**	telephone	**bowl**	telephone
11	E	cat	**aeroplane**	**aeroplane**	cat
12	F	**cake**	sofa	cake	**sofa**
13	F	apple	**boots**	**apple**	boots
14	D	**swing**	brush	brush	**swing**
15	C	bird	**pushchair**	bird	**pushchair**
16	E	**nappy**	banana	**banana**	nappy
17	B	cup	**chair**	**sheep**	star
18	A	**duck**	car	**foot**	balloon
19	A	coat	**bed**	frog	**ear**
20	B	**fish**	truck	slide	**milk**
21	E	biscuit	**trousers**	trousers	**biscuit**
22	C	**TV**	strawberry	**TV**	strawberry
23	D	keys	**grape**	**grape**	keys
24	F	**elephant**	bicycle	elephant	**bicycle**

Note: Target = bold font and underline

Table E.7. Experiment 5–Test List 3b.

C2	Condition	*Left*	Prime	*Right*	*Left*	Probe	*Right*
1	F	**apple**		boots	apple		**boots**
2	D	swing		**brush**	**brush**		swing
3	C	**bird**		pushchair	**bird**		pushchair
4	E	nappy		**banana**	banana		**nappy**
5	B	**cup**		chair	sheep		**star**
6	A	duck		**car**	foot		**balloon**
7	A	**coat**		bed	**frog**		ear
8	B	fish		**truck**	**slide**		milk
9	E	**biscuit**		trousers	**trousers**		biscuit
10	C	TV		**strawberry**	TV		**strawberry**
11	D	**keys**		grape	grape		**keys**
12	F	elephant		**bicycle**	**elephant**		bicycle
13	F	**cow**		train	cow		**train**
14	D	raisins		**windows**	**windows**		raisins
15	C	**toast**		flower	**toast**		flower
16	E	ball		**shoes**	shoes		**ball**
17	B	**chicken**		boat	stairs		**arm**
18	A	table		**bag**	hand		**pig**
19	A	**dog**		bus	**spoon**		tree
20	B	door		**toothbrush**	**book**		lion
21	E	**sock**		bath	**bath**		sock
22	C	bowl		**telephone**	bowl		**telephone**
23	D	**cat**		aeroplane	aeroplane		**cat**
24	F	cake		**sofa**	**cake**		sofa

Note: Target = bold font and underline

Table E.8. Experiment 5–Test List 4a.

D1	Condition	*Left*	Prime	*Right*	*Left*	Probe	*Right*
1	D	**train**		cow	cow		**train**
2	C	windows		**raisins**	windows		**raisins**
3	E	**flower**		toast	**toast**		flower
4	B	shoes		**ball**	**pig**		hand
5	A	**boat**		chicken	**tree**		spoon
6	F	bag		**table**	**bag**		table
7	F	**bus**		dog	bus		**dog**
8	A	toothbrush		**door**	lion		**book**
9	B	**bath**		sock	ear		**frog**
10	E	telephone		**bowl**	bowl		**telephone**
11	C	**aeroplane**		cat	**aeroplane**		cat
12	D	sofa		**cake**	**cake**		sofa
13	D	**boots**		apple	apple		**boots**
14	C	brush		**swing**	brush		**swing**
15	E	**pushchair**		bird	**bird**		pushchair
16	B	banana		**nappy**	**arm**		stairs
17	A	**chair**		cup	**balloon**		foot
18	F	car		**duck**	**car**		duck
19	F	**bed**		coat	bed		**coat**
20	A	truck		**fish**	milk		**slide**
21	B	**trousers**		biscuit	star		**sheep**
22	E	strawberry		**TV**	TV		**strawberry**
23	C	**grape**		keys	**grape**		keys
24	D	bicycle		**elephant**	**elephant**		bicycle

Note: Target = bold font and underline

Table E.9. Experiment 5–Test List 4b.

D2	Condition	*Left*	**Prime**	*Right*	*Left*	**Probe**	*Right*
1	D	boots		**apple**	**apple**		boots
2	C	**brush**		swing	**brush**		swing
3	E	pushchair		**bird**	bird		**pushchair**
4	B	**banana**		nappy	arm		**stairs**
5	A	chair		**cup**	balloon		**foot**
6	F	**car**		duck	car		**duck**
7	F	bed		**coat**	**bed**		coat
8	A	**truck**		fish	**milk**		slide
9	B	trousers		**biscuit**	**star**		sheep
10	E	**strawberry**		TV	**TV**		strawberry
11	C	grape		**keys**	grape		**keys**
12	D	**bicycle**		elephant	elephant		**bicycle**
13	D	train		**cow**	**cow**		train
14	C	**windows**		raisins	**windows**		raisins
15	E	flower		**toast**	toast		**flower**
16	B	**shoes**		ball	pig		**hand**
17	A	boat		**chicken**	tree		**spoon**
18	F	**bag**		table	bag		**table**
19	F	bus		**dog**	**bus**		dog
20	A	**toothbrush**		door	**lion**		book
21	B	bath		**sock**	**ear**		frog
22	E	**telephone**		bowl	**bowl**		telephone
23	C	aeroplane		**cat**	aeroplane		**cat**
24	D	**sofa**		cake	cake		**sofa**

Note: Target = bold font and underline

Table E.10. Experiment 5–Test List 5a.

E1	Condition	*Left* (Prime)	*Right* (Prime)	*Left* (Probe)	*Right* (Probe)
1	C	**train**	cow	**train**	cow
2	E	windows	**raisins**	raisins	**windows**
3	B	**flower**	toast	lion	**book**
4	A	shoes	**ball**	tree	**spoon**
5	F	**boat**	chicken	boat	**chicken**
6	D	bag	**table**	**table**	bag
7	D	**bus**	dog	dog	**bus**
8	F	toothbrush	**door**	**toothbrush**	door
9	A	**bath**	sock	**ear**	frog
10	B	telephone	**bowl**	**star**	sheep
11	E	**aeroplane**	cat	**cat**	aeroplane
12	C	sofa	**cake**	sofa	**cake**
13	C	**boots**	apple	**boots**	apple
14	E	brush	**swing**	swing	**brush**
15	B	**pushchair**	bird	milk	**slide**
16	A	banana	**nappy**	arm	**stairs**
17	F	**chair**	cup	chair	**cup**
18	D	car	**duck**	**duck**	car
19	D	**bed**	coat	coat	**bed**
20	F	truck	**fish**	**truck**	fish
21	A	**trousers**	biscuit	**pig**	hand
22	B	strawberry	**TV**	**balloon**	foot
23	E	**grape**	keys	**keys**	grape
24	C	bicycle	**elephant**	bicycle	**elephant**

Note: Target = bold font and underline

Table E.11. Experiment 5–Test List 5b.

E2	Condition	*Left*	**Prime**	*Right*	*Left*	**Probe**	*Right*
1	C	boots		**apple**	boots		**apple**
2	E	**brush**		swing	**swing**		brush
3	B	pushchair		**bird**	**milk**		slide
4	A	**banana**		nappy	**arm**		stairs
5	F	chair		**cup**	**chair**		cup
6	D	**car**		duck	duck		**car**
7	D	bed		**coat**	**coat**		bed
8	F	**truck**		fish	truck		**fish**
9	A	trousers		**biscuit**	pig		**hand**
10	B	**strawberry**		TV	balloon		**foot**
11	E	grape		**keys**	keys		**grape**
12	C	**bicycle**		elephant	**bicycle**		elephant
13	C	train		**cow**	train		**cow**
14	E	**windows**		raisins	**raisins**		windows
15	B	flower		**toast**	**lion**		book
16	A	**shoes**		ball	**tree**		spoon
17	F	boat		**chicken**	**boat**		chicken
18	D	**bag**		table	table		**bag**
19	D	bus		**dog**	**dog**		bus
20	F	**toothbrush**		door	toothbrush		**door**
21	A	bath		**sock**	ear		**frog**
22	B	**telephone**		bowl	star		**sheep**
23	E	aeroplane		**cat**	cat		**aeroplane**
24	C	**sofa**		cake	**sofa**		cake

Note: Target = bold font and underline

Table E.12. Experiment 5–Test List 6a.

F1	Condition	Prime		Probe	
		Left	*Right*	*Left*	*Right*
1	E	**train**	cow	**cow**	train
2	B	windows	**raisins**	**tree**	spoon
3	A	**flower**	toast	**lion**	book
4	F	shoes	**ball**	**shoes**	ball
5	D	**boat**	chicken	chicken	**boat**
6	C	bag	**table**	bag	**table**
7	C	**bus**	dog	**bus**	dog
8	D	toothbrush	**door**	**door**	toothbrush
9	F	**bath**	sock	bath	**sock**
10	A	telephone	**bowl**	pig	**hand**
11	B	**aeroplane**	cat	arm	**stairs**
12	E	sofa	**cake**	cake	**sofa**
13	E	**boots**	apple	**apple**	boots
14	B	brush	**swing**	**ear**	frog
15	A	**pushchair**	bird	**milk**	slide
16	F	banana	**nappy**	**banana**	nappy
17	D	**chair**	cup	cup	**chair**
18	C	car	**duck**	car	**duck**
19	C	**bed**	coat	**bed**	coat
20	D	truck	**fish**	**fish**	truck
21	F	**trousers**	biscuit	trousers	**biscuit**
22	A	strawberry	**TV**	balloon	**foot**
23	B	**grape**	keys	star	**sheep**
24	E	bicycle	**elephant**	elephant	**bicycle**

Note: Target = bold font and underline

Table E.13. Experiment 5–Test List 6b.

F2	Condition	*Left*	**Prime** *Right*	*Left*	**Probe** *Right*
1	E	boots	**apple**	apple	**boots**
2	B	**brush**	swing	ear	**frog**
3	A	pushchair	**bird**	milk	**slide**
4	F	**banana**	nappy	banana	**nappy**
5	D	chair	**cup**	**cup**	chair
6	C	**car**	duck	**car**	duck
7	C	bed	**coat**	bed	**coat**
8	D	**truck**	fish	fish	**truck**
9	F	trousers	**biscuit**	**trousers**	biscuit
10	A	**strawberry**	TV	**balloon**	foot
11	B	grape	**keys**	**star**	sheep
12	E	**bicycle**	elephant	**elephant**	bicycle
13	E	train	**cow**	cow	**train**
14	B	**windows**	raisins	tree	**spoon**
15	A	flower	**toast**	lion	**book**
16	F	**shoes**	ball	shoes	**ball**
17	D	boat	**chicken**	**chicken**	boat
18	C	**bag**	table	**bag**	table
19	C	bus	**dog**	bus	**dog**
20	D	**toothbrush**	door	door	**toothbrush**
21	F	bath	**sock**	**bath**	sock
22	A	**telephone**	bowl	**pig**	hand
23	B	aeroplane	**cat**	**arm**	stairs
24	E	**sofa**	cake	**cake**	sofa

Note: Target = bold font and underline

E.1 Extra Analyses

E.1.1 Conditions A vs. B

Pre-naming: Prime vs. Probe

To examine whether the probe pre-naming phase reflects any 'immediate after-effect' of distractor inhibition from the prime phase, a 2 (location: attended vs. ignored) x 2 (phase: prime vs. probe) repeated-measures ANOVA was carried out. If there were any immediate after-effect of distractor inhibition, we would observe less fixations at the ignored location (Condition B) than at the attended location (Condition A) in the probe pre-naming phase. The time course data in Figure 7.7 suggests a window between 300-1500ms would capture eye-fixations driven by pictures onset [1]. The ANOVA results indicate no significant main effects of location ($F(1, 31) = 0.861, p = .361$), suggesting that participants did not look less at the ignored location during the probe pre-naming phase. Mover, there was no significant main effect of phase ($F(1, 31) = 0.339, p = .565$) or interaction of location and phase ($F(1, 31) = 0.336, p = .567$). In other words, participants showed no immediate after-effect of distractor inhibition in the probe pre-naming phase, and did not respond differently in the prime and probe pre-naming phases.

[1] Growth curve analysis is inappropriate for the pre-naming window analysis because looking time was mainly zero before 300ms, and the time course is almost flat during 500–1000ms

E.1.2 Conditions C to F

Pre-naming: Prime vs. Probe

To examine whether the probe pre-naming phase fixation patterns reflects any 'immediate after-effect' from the prime phase, a 4 (Condition: C to F) x 2 (Phase: Prime vs. Probe) repeated-measures ANOVA was carried out. There was a significant main effect of condition ($F(3, 31) = 4.81, p = .004$). Post-hoc comparisons indicate that regardless of phase, there were significantly more fixations towards the ignored location–ignored identity picture (Condition F) than the attended location–attended identity (Condition C: $M_{difference} = 0.14, t(63) = 3.23, p = .002$), the ignored location–attended identity (Condition D: $M_{difference} = 0.11, t(63) = 3.13, p = .003$), and the attended location–ignored identity (Condition E: $M_{difference} = .09, t(63) = 2.52, p = .014$) [2]. There was, however, no significant main effect of Phase ($F(1, 31) = 0.85, p = .364$) or interaction of phase and condition ($F(3, 93) = 2.36, p = .077$).

Growth Curve Analysis

[2] this is marginally significant after Bonferroni correction, adjusted p value = .008

Table E.14. Experiment 5–Conditions C to F: Growth Curve Analysis. The attended location–attended identity condition (Condition C) and the prime phase were treated as baseline in the model, relative parameters were estimated for Condition D, E and F, and the probe phase fixation data.

Fixed Effects	**Model Terms**	**Est. (SE)**	t	p
Ignored Location–Attended Identity (Condition D)	Intercept	0.01 (0.07)	0.19	.8525
	Linear	-0.13 (0.25)	-0.51	.6075
	Quadratic	0.39 (0.25)	1.54	.1241
Attended Location–Ignored Identity (Condition E)	Intercept	-0.25 (0.08)	-3.22	.0013**
	Linear	0.39 (0.26)	1.50	.1348
	Quadratic	0.16 (0.26)	0.61	.5387
Ignored Location–Ignored Identity (Condition F)	Intercept	-0.22 (0.07)	-3.04	.0024**
	Linear	0.37 (0.25)	1.48	.1398
	Quadratic	0.03 (0.25)	0.12	.9023
Probe Phase	Intercept	0.05 (0.07)	0.63	0.5266
	Linear	1.49 (0.26)	5.77	<.001***
	Quadratic	-0.26 (0.26)	-1.02	.31
Ignored Location–Attended Identity (Condition D)*Probe Phase	Intercept	-0.27 (0.10)	-2.62	.0087**
	Linear	-0.84 (0.36)	-2.32	.0202*
	Quadratic	-0.42 (0.36)	-1.18	.2393
Attended Location–Ignored Identity (Condition E)*Probe Phase	Intercept	0.34 (0.11)	3.14	.0017**
	Linear	-1.06 (0.37)	-2.84	.0045**
	Quadratic	0.07 (0.37)	0.20	.8413
Ignored Location–Ignored Identity (Condition F)*Probe Phase	Intercept	0.53 (0.11)	5.04	<.001***
	Linear	-1.43 (0.36)	-3.93	<.001***
	Quadratic	-0.23 (0.36)	-0.63	.5302

$***p<.001, **p<.01, *p<.05$

C vs. D As seen in Figure E.1, there was a significant interaction of Attended Location–Attended Identity (Condition C)*Probe Phase on the intercept term (estimated value represented by the horizontal lines). In the attended location–attended identity condition (Condition C), there were similar amount of fixations in the prime and probe post-naming window. However, in the ignored location–attended identity condition (Condition D), there were significantly less fixations in the probe post-naming window than in the prime phase. Moreover, the significant linear term (see Table 7.4) indicates that the probe post-naming slope of target fixation in the attended location–attended identity (Condition C) was significantly steeper than that in the ignored location–attended identity condition (Condition D).

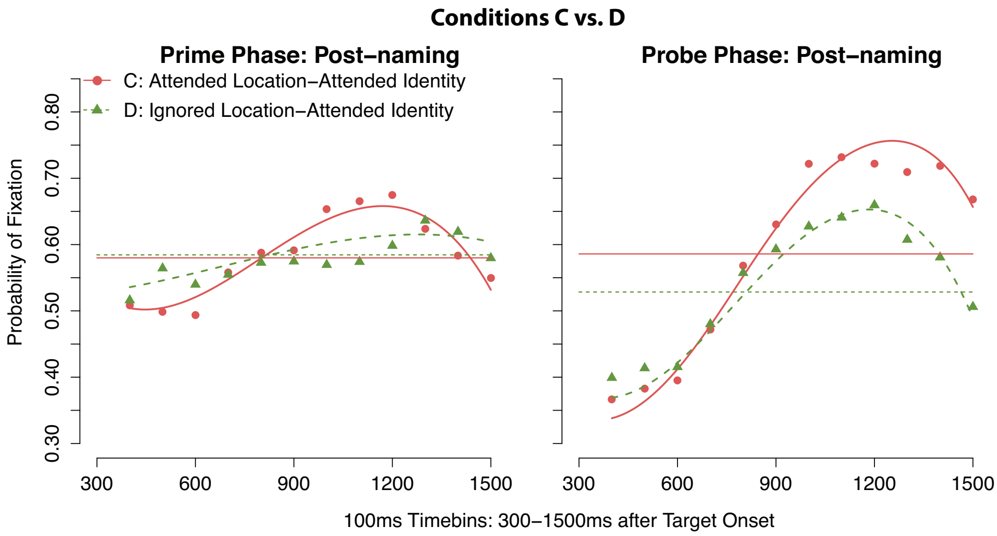

Figure E.1. Growth Curve Analysis: Illustrating the significant intercept term in the significant interaction of Condition C*Probe Phase. The full model is represented in curves, while the estimated intercept value is represented by the horizontal lines.

E vs. D Figure E.2 illustrates the a significant interaction of Attended Location–Ignored Identity (Condition E)*Probe Phase on the intercept term. Compared to the prime post-naming window, participants showed decreased amount of target fixation in the probe post-naming window in the ignored location–attended identity condition (Condition D), but increased target fixation in the attended location–ignored identity condition (Condition E).

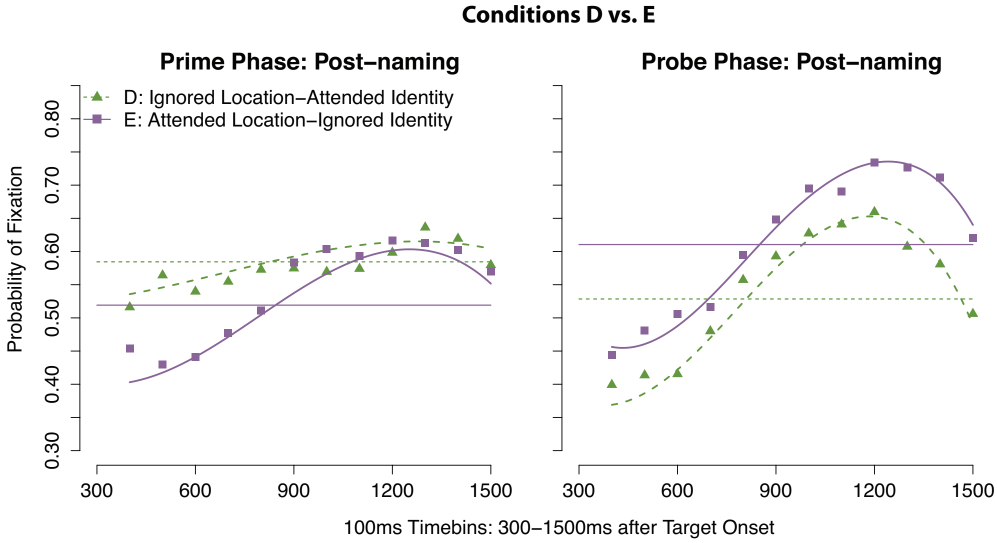

Figure E.2. Growth Curve Analysis: Conditions E vs. D.

D vs. F Figure E.3 illustrates the a significant interaction of Ignored Location–Ignored Identity (Condition F)*Probe Phase on the intercept term. Compared to the prime post-naming window, participants showed decreased amount of target fixation in the probe post-naming window in the ignored location–attended identity condition (Condition D), but increased target fixation in the ignored location–ignored identity condition (Condition F).

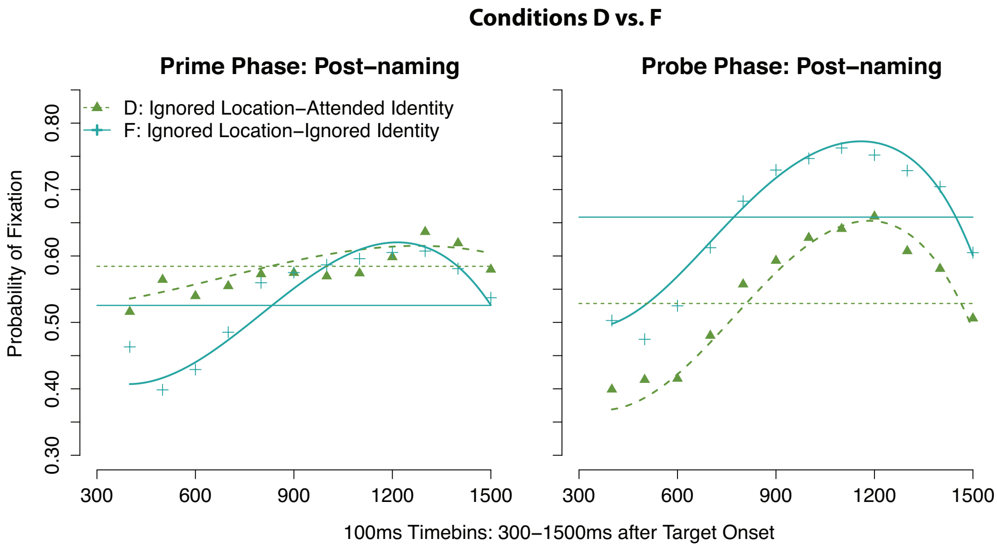

Figure E.3. Growth Curve Analysis: Conditions F vs. D.

C vs. E To further compare the interactions between conditions, I re-levelled the same model using the attended location–attended identity condition (Condition C) and prime phase as the baseline measurement [3].

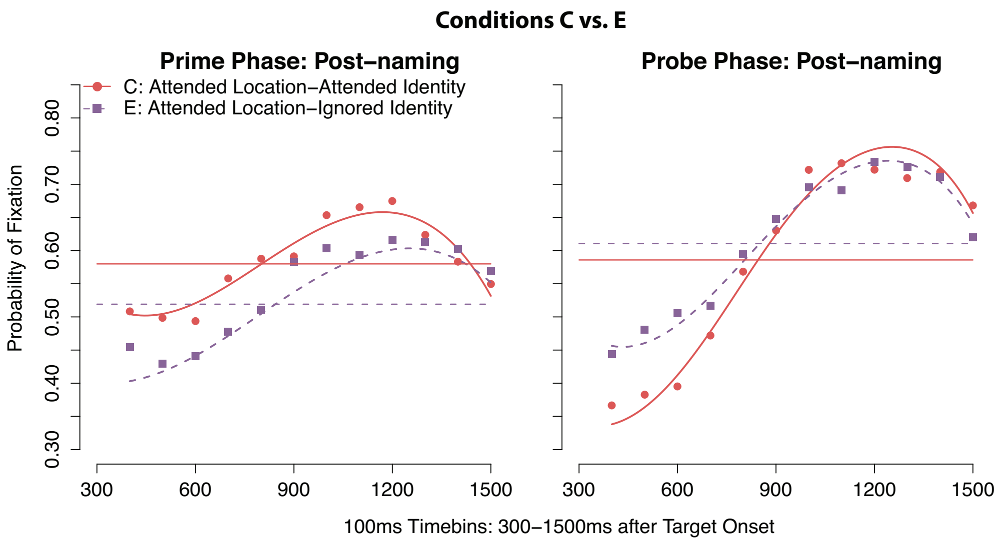

Figure E.4. Growth Curve Analysis: Conditions C vs. E.

There was a significant interaction of Attended Location–Ignored Iden-

[3] see Table E14 in Appendix E for full model output

tity (Condition E)*Probe Phase on the intercept term and linear term. As seen in Figure E.4, participants showed similar amount of target fixation in the prime and probe post-naming window in the attended location–attended identity condition (Condition C). In contrast, participants showed increased probe post-naming target fixation in the attended location–ignored identity condition (Condition E). However, we can see that the probe target fixation curves reached similar heights in both the attended location–attended identity condition (Condition C) and the attended location–ignored identity condition (Condition E) towards the end of the time course. In fact, the significant linear term indicates that the slope of probe target fixation in the attended location–ignored identity condition (Condition E) was less steep than that of the attended location–attended identity condition (Condition C), suggesting that target fixation in Condition C eventually 'caught up' with Condition E.

C vs. F Similarly, there was a significant interaction of Condition F*Probe Phase on the intercept term and linear term. As seen in Figure E.5, participants showed similar amount of target fixation in the prime and probe post-naming window in the attended location–attended identity condition (Condition C). In contrast, participants showed increased probe post-naming target fixation in ignored location–ignored identity condition (Condition F). However, we can see that the probe target fixation curves reached similar heights in both Conditions C and F towards the end of the time course. In fact, the significant linear term indicates that the slope of probe target fixation in Condition F was less steep than that of Condition C, suggesting that target fixation in Condition C eventually 'caught up' with Condition F.

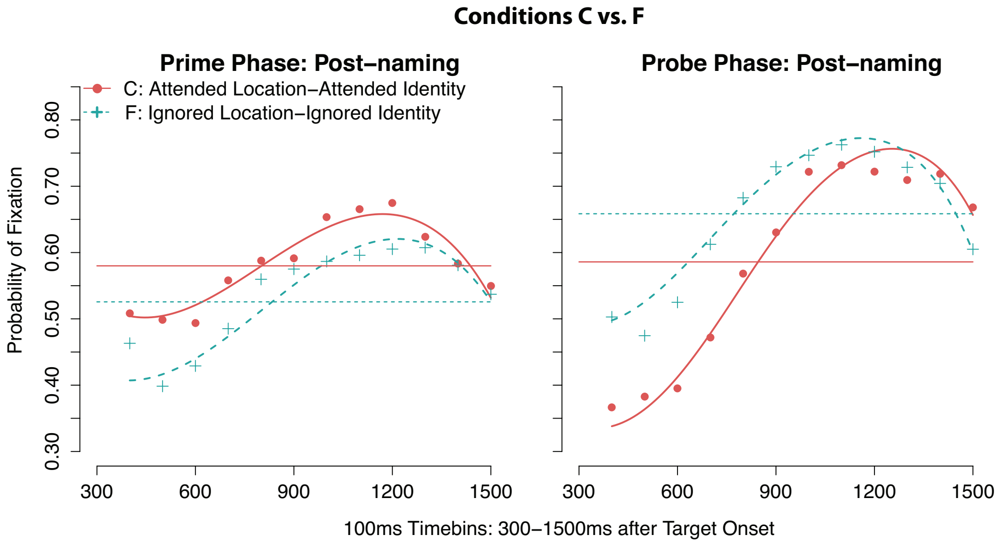

Figure E.5. Growth Curve Analysis: Conditions C vs. F.

Table E.15. Experiment 5–Conditions C to F: Growth Curve Analysis. The attended location–ignored identity condition (Condition E) and the prime phase were treated as baseline in the model, relative parameters were estimated for Condition C, D and F, and the probe phase fixation data.

Fixed Effects	**Model Terms**	**Est. (SE)**	***t***	***p***
Attended Location–Attended Identity (Condition C)	Intercept	0.25 (0.08)	3.22	.0013**
	Linear	-0.39 (0.26)	-1.50	.1348
	Quadratic	-0.16 (0.26)	-0.61	.5387
Ignored Location–Attended Identity (Condition D)	Intercept	0.26 (0.10)	3.41	<.001***
	Linear	-0.52 (0.26)	-1.99	.0465*
	Quadratic	0.23 (0.26)	0.87	.3864
Attended Location–Ignored Identity (Condition F)	Intercept	0.02 (0.08)	0.30	.7625
	Linear	-0.02 (0.26)	-0.07	.9403
	Quadratic	-0.13 (0.26)	-0.50	.6189
Probe Phase	Intercept	0.39 (0.08)	4.91	<.001***
	Linear	0.42 (0.27)	1.55	.1202
	Quadratic	-0.19 (0.27)	-0.69	.4915
Attended Location–Attended Identity (Condition C)*Probe Phase	Intercept	-0.34 (0.11)	-3.14	.0017**
	Linear	1.06 (0.37)	2.84	.0045**
	Quadratic	-0.07 (0.37)	-0.20	.8413
Ignored Location–Attended Identity (Condition D)*Probe Phase	Intercept	-0.62 (0.11)	-5.72	<.001***
	Linear	0.23 (0.37)	0.62	.5383
	Quadratic	-0.50(0.37)	-1.35	.1780
Attended Location–Ignored Identity (Condition F)*Probe Phase	Intercept	0.19 (0.11)	1.77	.0763
	Linear	-0.36 (0.37)	-0.97	.3324
	Quadratic	-0.30 (0.37)	-0.81	.4171
				$***p<.001, **p<.01, *p<.05$

E vs. F Finally, I re-levelled the same model using the attended location–ignored identity condition (Condition E) and prime phase as the baseline measurement [4]. The results indicate no significant interaction effect of Ignored Location–Ignored Identity (Condition F)*Probe Phase. As seen in Figure E.6, target fixation in the attended location–ignored identity condition (Condition E) and ignored location–ignored identity condition (Condition F)

[4] see Table E15 in Appendix E for full model output

followed similar trajectories in the prime phase. In the probe phase, target fixation increased in both Condition C and F.

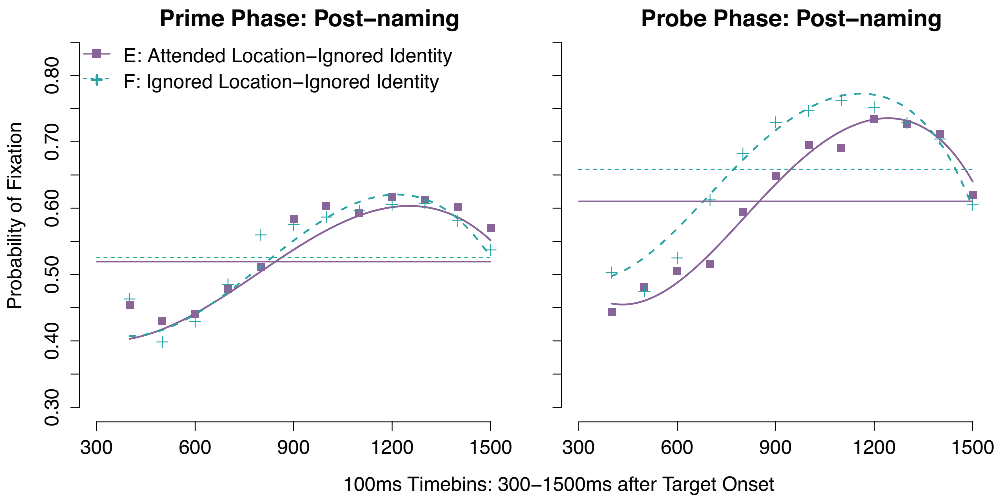

Figure E.6. Growth Curve Analysis: Conditions E vs. F.

Summary The growth curve analysis indicates that there was significantly greater amount of target fixation in the probe phase than in the prime phase. However, there was a significant interaction of Condition and Phase. In the attended location–attended identity (Condition C), the overall amount of post-naming target fixations were similar in the prime and probe phases. In the ignored location–attended identity (Condition D), there were overall less amount of post-naming target fixations in the probe phase than in the prime phase. In both the attended location–ignored identity (Condition E) and ignored location–ignored identity (Condition F), there were overall greater amount of post-naming target fixations in the probe phase than in the prime phase. It is worth noting that the slope of the attended location–attended identity condition (Condition C) was significantly steeper than other other three conditions. This is because despite its lower baseline at target word onset, the curve of Condition C reached a similar peak compared to the attended location–ignored identity condition (Condition E) and the ignored location–ignored identity condition (Condition F). In contrast, the slope in the ignored location–attended identity condition (Condition D) never reached the same height of peak as the other three conditions. In sum, the growth curve analysis suggest impaired target fixation in the ignored location–attended identity condition (Condition D) compared to the other three conditions.

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