Exploration of multiple memory processes in children's mapping and generalising of novel nouns

Maria Eleni Bakopoulou
100163087
School of Psychology
University of East Anglia

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Abstract

Young children typically acquire vocabulary, particularly names for things, at a rapid pace during toddlerhood. Prior research suggests that children's word learning is influenced by multiple factors including the amount of input they hear, their own motivation, temperament, and a host of cultural factors. Attention and memory processes may also be related to differences in children's vocabulary development. In particular, a long line of research suggests that when toddlers learn new names, they demonstrate biases to attend to some features of objects more than others. Aspects of memory for visual stimuli and object processing may be particularly relevant for learning object names. The present thesis aims to further advance our understanding of the relation between attention, and visual memory at multiple timescales by investigating three research questions. Firstly, how the automatic allocation of attention when generalising novel nouns is related to vocabulary. Secondly, what is the relationship between object memory and early vocabulary development. Thirdly, what is the relationship between shape bias, children's vocabulary, visual attention, and multiple memory timescales. Key findings include a replication of prior work showing that more attention to the shape of objects is positively related to vocabulary and that nouns cue attention to shape; that it might be the relative size of the vocabulary, rather than absolute number of words known, that is related to object memory; and that there is a relation between visual working memory and retention of new name-object mappings, but only for children with smaller vocabularies. Overall, the data

presented in this thesis contribute to memory and vocabulary development research by confirming relations between attention allocation in naming tasks and vocabulary and between memory at multiple timescales and word learning. Our results set the stage for future work on word learning and multiple memory types, essential in understanding word learning development.

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Chapter 1

Introduction

Acquiring language is an enormous and difficult task. As they develop, children acquire the rules of grammar, the rhythm of language and the power of communication. One clear and exciting marker that language learning is underway is a child's production of their first word, typically between 10- and 12-months of age. However, this milestone of development typically follows much earlier evidence of word comprehension that begins at around 4- to 6-months of age as children orient to their own name (Visser-Bochane, Reijneveld, Krijnen, van der Schans, & Luinge, 2020) and show recognition of everyday words (Karmiloff & Karmiloff-Smith, 2009; Kidd & Donnelly, 2020). Following the production of the first words, vocabulary development proceeds slowly, although many children display a "spurt" in their expressive vocabulary during the second year of life, between the ages of 20 and 24 months (Fenson et al., 1994). In this period there is also initial evidence that the child's grasp of vocabulary does not stop at single words, as children show evidence of understanding word order (de la Cruz-Pavía, Marino, & Gervain, 2021) and being able to produce simple two-word combinations (Berk & Lillo-Martin, 2012).

Throughout the toddler period, the majority of a child's vocabulary is comprised of nouns. Nouns are the first words children usually learn, as they are less complex than verbs (Druks, 2002; Gershkoff-Stowe & Smith, 2004). Nouns are also like sturdy "stones" that form the foundation for development of other kinds of words in the vocabulary, such as adjectives and verbs. Verbs are "action" words that depict actions and movements, and adjectives are "describing" words that add detail, colour and nuance to the child's understanding. However, they are harder to grasp and are a secondary stage in the child's vocabulary learning. Nouns support this learning by providing a concrete reference point around which extra descriptive and action-related vocabulary can be developed. For example, if the child knows the word 'ball' they can use this knowledge to help determine that "get the blue ball" indicates something about their favourite toy (c.f., Carey, 1978). Thus, nouns serve as the anchors, grounding children's ability to learn the concepts associated with more difficult and abstract words they need to add to their vocabulary.

As vocabulary development progresses, the child continues to add nouns and other types of words, such as verbs and adjectives, at a steady pace through the preschool years, typically reaching between 1,000 and 10,000 words upon school entry (Fenson et al., 2007; Shipley & McAfee, 2015). However, while these general metrics of timing and amount of word learning for children generally are well attested in the literature, vocabulary development is, in fact, a unique journey for every child. While some children seem to build vocabularies effortlessly and rapidly, others take a slower and more measured approach (Huttenlocher, Newcombe, & Vasilyeva, 1999). Research has found that word learning draws on many processes and is shaped by various inputs (Samuelson, 2021).

Factors that have been shown to predict word learning and early language development include the language environment at home (Hoff, 2006) and aspects of parent–child interactions, such as the level of joint attention (Tomasello, 1988), the degree of parental responsive behaviour (Donnellan, Bannard, McGillion, Slocombe, & Matthews, 2019) and the child's ability to maintain attention (Yu, Suanda, & Smith, 2019). But there are still critical questions about how children learn new words in terms of the many cognitive factors that support this learning, how input and processes interact, and how this varies across children. One goal of the current work is to contribute to understanding of how multiple processes come together to support early vocabulary development and provide some insight on differences between children's vocabulary development trajectories.

1.1 Early Word Learning and Vocabulary Development

The impressive building of vocabulary through infancy and the preschool period masks the challenge presented for a child. Even in the case of learning a concrete object noun, multiple processes are involved. To learn the word "cup", when mum says "Here's your cup", the child has to divide the word from the speech stream, identify the cylindrical drinking object as the target and make an association between the two. The difficulty of this task was famously argued by Quine (1960) who suggested that one of the compounding factors in understanding what a single new word means is the seemingly limitless possibilities for mapping between a word and the possible referents. Quine (1960) suggested an example in the context of a field linguist, researching a community with an unfamiliar language. While hunting with some local tribesmen, a rabbit suddenly leaps by and one of the tribesmen exclaims

"Gavagai". There is no certainty as to whether he means 'rabbit' or other possibilities such as "hopping", "fluffy" or "get it!".

The idea exemplified by the example of the field linguist is known as the "Gavagai" problem (Quine, 1960), which shows that there are infinite possible meanings of a word. Similar to the field linguist, how is the child to know if the new word "cup" refers to the cylindrical object, the substance inside the object, or the act of consuming what is in the cylindrical object? Historically, the field's answer to this question was to propose that children used a number of word learning biases to support early vocabulary development (see Samuelson & McMurray, 2017; Markman, 1990, for review). These biases include taxonomic bias, novelty bias, mutual exclusivity and shape bias.

The taxonomic bias refers to a child's ability to apply labels to similar objects, underscoring the role of categorisation in early word learning (Gelman, Croft, Fu, Clausner, & Gottfried, 1998). For example, when children group animals together, they might label different kinds of novel four-legged animals, such as dogs, and cats, under the broader category of "animals". Markman and Hutchinson (1984) proposed that when children make such an extension, they are doing so on the basis of the assumption that words refer to taxonomically organised categories. Thus, labels refer to objects of the same kind of shared characteristics rather than to objects that are thematically related. This kind of bias would help children in vocabulary development as it will allow them to extend their vocabulary further, for example learn more animals by categorising objects based on shared characteristics (Markman & Hutchinson, 1984; Markman, 1994). However, this bias might also limit the diversity of categories children learn by focusing too heavily on grouping objects by shared characteristics, potentially neglecting functional or thematic relations that are also crucial for cognitive development. This might restrict broader understanding and application in different contexts, where knowing how things are used or related to real-world scenarios is important (Markman & Hutchinson, 1984).

Children exhibit a pronounced novelty bias, a preferential interest in novel stimuli, across various domains, including word learning. The novelty bias operates by directing attentional resources towards new information. Further, it has been suggested that the heightened attention facilitates the formation of stronger word–object associations through enhanced encoding and processing (Hunnius, 2007). In the context of word learning, this bias suggests that children are more likely to attend to, encode and learn the names of novel objects, events or concepts compared with familiar ones (Axelsson, Horst, Playford, & Winiger, 2023; Kucker, McMurray, & Samuelson, 2018). For example, Kucker et al. (2018) evaluated the processes involved in identifying the referent of novel words in young children. They conducted two experiments in order to examine 18-month-old children's performance in referent selection and retention with novel and known words. They found that young children exhibit a strong bias towards selecting novel items as referents when learning new words. This novelty bias influences their in-the-moment choices. However, while the novelty bias may not guarantee long-term retention of word-meaning associations (Kucker et al., 2018), it does play a crucial role in early vocabulary development, as supported by studies with both infants and toddlers (Gómez & Gerken, 2000). Coversely, novelty bias is not static. As vocabulary knowledge expands, children develop the ability to discern meaning based on context rather than relying solely on novelty (Golinkoff, Mervis, & Hirsh-Pasek, 1994; Samuelson & McMurray, 2017).

Another bias is mutual exclusivity, which explains how young children "fast-map" novel names to novel objects by rejecting additional associations to a name-known object. It is another bias used to help children identify the meanings of new words (Houston-Price, Caloghiris, & Raviglione, 2010). Swingley (2010) noted that fast mapping allows children to understand and retain word meanings based on indirect and incomplete evidence. Notably, the mutual exclusivity bias has been suggested to stem from a more general principle, either a one-to-one mapping principle between words and their referents or the uniqueness principle applied to word learning (Sia, Holmboe, & Mani, 2023). This means children intuitively reject the possibility of multiple labels for the same object, particularly at the outset of their linguistic journey (Markman & Wachtel, 1988). By assuming unique labels for new objects they encounter, children avoid confusion with already learned words, streamlining vocabulary acquisition. Sia et al. (2023) argue that mutual exclusivity fuels "fast-mapping": the rapid association of novel names with novel objects. Carey and Bartlett (1978) study demonstrated fast mapping, as children could comprehend or produce novel words immediately after even one exposure. This was shown when pre-schoolers successfully selected an olive-green tray when their preschool teachers gestured to two trays and asked them to get "the chromium tray, not the blue one, the chromium one" (Carey, 1978; Carey & Bartlett, 1978). They understood the assumption that the novel word was referring to the colour of the tray. Thus, they demonstrated that children could use the information provided in the task to determine the referent of a novel word even after a single entry.

Much work has demonstrated that children can form initial mappings between a novel word and an unfamiliar object when the novel word and object are presented in the context of previously known words and objects. However, work suggests these mappings are not immediately added to the lexicon. Horst and Samuelson (2008) carried out a referent selection task, showing children sets of both familiar and novel ones and asking them to get them with either familiar or novel names. After a 5-min delay the children were tested for retention of the novel word-object mappings. Horst and Samuelson (2008) found that even though 24-month-old children performed well at referent selection, they did not demonstrate evidence of having retained new word-object mappings from this fast-mapping task after a 5-minute delay.

While these findings contradict the idea that children "learn" new words from limited exposures, they can be understood to fit with Carey's (1978) original idea that integrating new words into the vocabulary requires both fast and slow mapping them (Carey, 1978; Carey & Bartlett, 1978). They need fast-mapping to create a link between the words and referents which is then followed by slow mapping in order to build on these memories and help with generalisation. (Kucker & Samuelson, 2012) asked what helps children bridge from initial fast mappings to longer term retention. They allowed children to familiarise themselves with either the novel object or the novel object name prior to a reference selection task, in which they pitted two name-known objects against a novel object. They found that only children allowed to familiarise themselves with the objects demonstrated retention of the new mappings after a delay. The study showed that infants' familiarity with novel objects enhanced their capacity to retain word-object mappings, shedding light on the early stages of word learning. Their finding showed that object familiarisation aids retention for multiple word object pairings.

The basis of children's fast-mapping abilities has been debated, however Mather and Plunkett (2012) argued that fast mapping was based on the novelty bias rather than mutual exclusivity. They pointed out that in most studies of fast-mapping the object that did not have a name and thus was the target was also the most novel. To investigate this hypothesis, they used preferential-looking tasks where infants were presented with three objects: one with a known name and two without names, where one of the name-unknown objects was novel, and the other had been previously familiarised. They found that infants in this context infants selected the most novel object as the referent of a novel name, even though the other objects also did not have names associated with them. Mather and Plunkett (2012) concluded that infants' preference for novelty, and not just avoidance of lexical overlap, plays a crucial role in infants' ability to map new words to objects. When infants are presented with novel labels, their attention is increased to novel, name-unknown objects over familiar ones. This suggests that novelty processing is an important mechanism in early word learning, and it may operate alongside other cognitive processes to support vocabulary acquisition.

This finding aligns with the study by Horst, Samuelson, Kucker, and McMurray (2011), which demonstrated that infants' preference for novel objects can override the mutual exclusivity constraint they typically exhibit. Horst et al. (2011) familiarised children with previously novel objects. Then, they conducted a novel name referent selection trials where children were asked to select the referent from three novel objects: two previously seen and one completely novel object. Children demonstrated a clear bias to select the most novel object. A second experiment controlled for pragmatic responding and replicated the initial finding. From these findings they concluded that children's referent selection is biased by previous exposure and children's endogenous bias to novelty.

Relatedly, Mather and Plunkett (2009) examined the development of biases over time in younger children. They used an intermodal preferential looking task to investigate whether infants could use mutual exclusivity to guide their association of novel labels with novel objects. They presented infants with a familiar and novel object accompanied with one of three types of auditory stimulus: familiar label trials, presenting the name for the familiar object, novel label trials, presenting a novel label for the novel object, and control trials, presenting a neutral phrase. The trials were split into two halves; a different set of object images and labels were presented in each half. Each half was further divided into two blocks of six trials. The first block of trials presented two examples of each trial type: two familiar label trials, two novel label trials, and two control trials. The second block of trials presented the same sequence of trials as the first block, counterbalancing for the side of the presentation. Therefore, for a given trial there was an original trial in the first block and a repeat trial in the second block. Because the second block presented trials in the same order as the first block, there was always a distance of six trials between the original and repeat presentations of a trial. Their results showed that when the infants were firstly exposed to a novel label with one familiar object and one novel object, looking behaviour was unsystematic. However, on re-exposure to the same stimuli, older children looked preferentially at the novel object prior to the re-presentation of the novel label. These findings suggest that novelty plays a crucial role in how infants acquire words enabling mutual exclusivity to emerge across repeated exposures to potential referents. This suggests that the attraction to novel objects facilitates the mapping of new words to these objects, more than previously understood.

Another bias shown to develop and change with early word learning is the shape bias. This refers to the tendency to generalise novel names for novel objects according to a similarity in shape. It is an attentional and word-learning bias (Samuelson & Smith, 1999). More than 30 years of research on shape bias has produced a clear theoretical framework linking the bias development to statistical regularities in the early noun vocabulary (Samuelson, 2002; Perry

& Samuelson, 2011). Smith, Jones, Landau, Gershkoff-Stowe, and Samuelson (2002) propose that shape bias may be the learned product of the early noun vocabulary. The idea begins with the fact that the nouns children learn early typically refer to concrete things, that are organised into categories with similar shapes, e.g., "balls" are typically round, and "cups" are cylinders. It is only after having learned some number of these that children start to show a bias to generalise new names for novel objects by similarity in shape (Samuelson & Smith, 1999; Smith, 2003; Perry & Samuelson, 2011). Further, once they develop a shape bias, their vocabularies tend to expand faster (Smith et al., 2002; Sims, Schilling, & Colunga, 2013; Samuelson, 2002; Vlach, 2016; Borgström, von Koss Torkildsen, Sahlén, & Lindgren, 2019). In one of the first demonstrations of this idea, (Smith et al., 2002) showed that teaching children, who did not yet demonstrate a shape bias, names for categories well organised by similarity in shape produced a precocious shape bias and accelerated their subsequent vocabulary learning (see also Samuelson, 2002; Perry, Samuelson, Malloy, & Schiffer, 2010).

It has also been suggested that after children acquire a shape bias, a similar mechanism of learning from regularities in the naming context and associated object properties can help children learn names for categories organised in other ways as well as other kinds of words (Jones & Smith, 1993). For example, while the naming context of common concrete things ("a cup", "a ball") would create an association between "a" and concrete objects in categories organised by similarity in shape; the fact that nonsolid things are named with other syntax "some pudding" or "a glass of water", and these things are in categories organised by similarity in material substance, could help children learn to attend to material when naming nonsolids (Perry, Custode, Fasano, Gonzalez, & Valtierra, 2022; Colunga & Smith, 2000). Likewise, the fact that properties of objects are pointed out with other syntactic contexts, e.g., "a blue one" or "a shiny one", could help children learn to attend to the surface properties in such naming contexts (Colunga & Smith, 2000). In this way, the developmental origins of the shape bias and related word learning biases could be cued by aspects of the syntax, tying these biases to more general cognitive processes—statistical learning and/or associative learning. It is well known that infants can learn to find words in the continuous speech stream by picking up on the statistical regularities of the sounds that tend to follow each other (Saffran, Aslin, & Newport, 1996; Saffran & Kirkham, 2018) for recent evidence see. The shape bias may similarly depend on infants picking up on regularities in what tends to follow in language.

Another general cognitive process suggested to support early vocabulary development is hypothesis testing. Here, the idea is that when exposed to a novel word and multiple possible referents, children create an initial hypothesis as to what the correct word object mapping is and either revise or confirm those hypotheses when presented with further evidence (Trueswell, Medina, Hafri, & Gleitman, 2013). Most recently this idea has been articulated in the context of cross situational word learning (CSWL) which demonstrates that children can learn object names over multiple ambiguous exposures, despite the moment-to-moment uncertainty as to the correct word-object mappings. The CSWL task involves the presentation of two objects and two words without indication of which word goes with which object. In the course of a number of such trials, however, the word that goes with a specific object is only said when the object is presented, allowing the correct mapping to be determined over multiple trials (Smith & Yu, 2008). Infants between 11- and 14-months of age have been shown to learn up to four new word object mappings in such tasks (Smith & Yu, 2008). According to one hypothesis testing account of this, learning proceeds by proposing a potential mapping for a given word when it is presented and then verifying or rejecting this hypothesis when the word is later presented again (Trueswell et al., 2013). In this way, hypothesis testing would help children learn words in this context by allowing them to form, test, and refine predictions about word-object mappings based on repeated exposure across different contexts.

Thus, in addition to specific biases supporting early vocabulary development, more general cognitive processes, like statistical learning and hypothesis testing have been argued to be critical to the early building of word knowledge (Saffran & Kirkham, 2018). A crucial issue, however, is whether the action of these biases can explain the variability seen in children's vocabulary development. Not all children follow a uniform developmental pace, and some children do not make rapid gains and have much smaller expressive and/or receptive vocabularies than the average (MacRoy-Higgins & Montemarano, 2016; Rescorla, 2011).

1.2 Individual Differences in Vocabulary Development

There are wide individual differences in children's vocabulary development with many children not making rapid of gains in vocabulary development and having much smaller expressive and/or receptive vocabularies than average. One group that has received focused attention in the field is "late talkers". Late talkers have been defined as children whose vocabulary development is slower and who have much smaller expressive and/or receptive vocabularies than average (MacRoy-Higgins & Montemarano, 2016; Rescorla, 2011; Perry & Samuelson, 2011; Perry, Kucker, Horst, & Samuelson, 2022). Research has defined “late talkers” as children who have a low percentile for their age and gender; ranging from below 15th to below the 30th percentile depending on the study (Thal, Bates, Goodman, & Jahn-Samilo, 1997; Rescorla & Achenbach, 2002; MacRoy-Higgins & Montemarano, 2016; Rescorla, 2011; Jones, 2003; Rescorla, Roberts, & Dahlsgaard, 1997).

In their study, Armstrong et al. (2017) extensively examined the variability in language development trajectories among late talkers. Late talking at age 2 is a key predictor of later language difficulties, with their research revealing that while some late talkers improve by age 10, a significant number continue to struggle. Armstrong et al. (2017) found that 5.6% of children consistently displayed low language skills, and 23.2% experienced a decline in language abilities between ages 2 and 10. This variation was associated with several factors, including maternal smoking during pregnancy, lower paternal education, and low family income. Additionally, children in poorer literacy environments, particularly boys, were more likely to show deteriorating language skills. The study underscores the importance of early identification of these modifiable risk factors, with maternal smoking emerging as a significant predictor of both consistently low and declining language skills. However, the exact mechanisms through which these factors impact language development remain to be fully understood.

In addition to external factors, such as the home environment and parental education, it has also been suggested that individual differences in learning styles and cognitive abilities influence how children acquire vocabulary, including how they utilise word learning biases (Perry & Samuelson, 2011; Gibson, Congdon, & Levine, 2015). Some may lean heavily on novelty, while others may adhere more rigidly to the one-to-one mapping rule (Gómez & Gerken, 2000). Thus, it is possible that differences in the biases different children emphasise may relate to differences in the specifics of their vocabulary development trajectories, and to some children being “late talkers”. And there is some evidence that children who are slower to build vocabulary as toddlers use word learning biases differently, resulting differences in vocabulary structure, compared to children on more typical vocabulary development trajectories (Colunga & Smith, 2008; Kucker, Braun, & Markham-Anderson, 2023).

For example, Yurovsky, Bion, Smith, and Fernald (2012) found that the vocabulary structure of late talkers is characterised by lack of semantic networks which is associated with slower language-learning. Yurovsky et al. (2012) had children complete reference selection trials. They found that those who displayed a mutual exclusivity bias performed better in selecting the correct novel object, indicating successful word learning through disambiguation. They argued that mutual exclusivity can help explain small structures of semantic networks, and the children who show mutual exclusivity will have more large structured networks and, thus, more connected words than those who do not. This results in different semantic network structures in children exhibiting mutual exclusivity compared to children who do not, even though they might have the same number of words in their vocabulary. Late-talking children likely have less optimally structured networks. The atypical semantic network structure which are characterised by fewer connections and less efficient organisation, is linked to slower language learning, which may hinder their ability to learn new words efficiently. These results point to a potential intervention for late-talking children. Thus, the use of mutual exclusivity could help children who are late talkers to improve their language abilities.

Just as there are different children with typical and slower vocabulary development with the application of mutual exclusivity, (Perry & Kucker, 2019), suggest late-talkers exhibit a different pattern of reliance on shape cues compared to typically developing children. In this study, they demonstrated that late-talkers are less likely to generalise new words based on the shape of objects, which contrasts with the strong shape bias observed in children who develop language along a typical trajectory. The research involved presenting children with objects and asking them to apply new words to similar-shaped objects. Late-talkers showed reduced efficiency in using shape as a cue, suggesting that their word learning strategies might rely less on shape information.

Another study that looked at shape bias in late talkers was by Colunga and Sims (2012), who aimed to understand how word learning biases could impact children's language development. They trained computational models previously used by Colunga and Smith (2005), on vocabularies of either early-talking children or late-talkers. They then tested the models on learning of new words. They found that all networks trained with early-talker vocabularies showed a shape bias for solids, and some early talker networks showed a material bias for non-solids as well. However, only some late talker networks showed a shape bias for solids and very few showed a material bias for non-solids. In their second experiment, they tested predictions from the models on children in a novel noun generalisation task. Overall, they found a difference in the performance between late talkers and typically developing children. Children who were late talkers generalised fewer words as they showed a shape bias for solids that was over-generalised to non-solids, too. This confirmed the neural network results that the differing vocabularies of early and late talkers create different word learning biases, which could then influence subsequent vocabulary development.

While the differences between children who are learning words more or less quickly with the use of biases such as mutual exclusivity and the shape bias may contribute to differences in vocabulary development among children, it remains unclear if this factor alone adequately explains the range of observed differences. Partly in response to the question of variability in development and partly driven by theoretical and technical changes in the field, there has been a shift away from word learning biases and towards an appreciation of multiple processes in supporting early vocabulary development. Theoretical changes include increased appreciation of the child's impressive learning abilities, including statistical learning (Saffran & Thiessen, 2003; Saffran et al., 2008; Aslin, 2017), as well as arguments about the role of the child's active embodied engagement in the learning task (Smith & Gasser, 2005; Smith & Yu, 2008). Technical changes include the use of head-mounted cameras and eye trackers that provide a better view of the input to children and computational modelling work supporting arguments for basic processes underpinning early learning (McMurray, Horst, & Samuelson, 2012; Gogate, Maganti, & Laing, 2013).

These changes have shifted the field from arguments about the action of specific biases or shifts from one bias to another as the basis of early vocabulary learning, to examinations of the multiple cognitive processes supporting early word learning. For example, Rose, Feldman, and Jankowski (2009) used a large test battery to assess memory, representational competence, processing speed and attention in a cohort of infants. These information-processing abilities at 12 months predicted language at 36 months, independently of earlier language scores (Rose et al., 2009). This supports the view that developments in general cognitive capacity support language acquisition. This thesis is inspired by these approaches in the field and looks at the role of attention and memory in children's learning and generalisation of new words. In the next sections, we review recent literature on the role of these processes in early vocabulary development, including the attentional processes that helps children determine the critical features of a referent and the memory processes that help them remember the object and the mapping.

1.3 Multiple general processes support early word learning

As reviewed above, one response to the question of how children learn words, given that mapping the correct referent to the word “banana” when mum introduces a new food at the breakfast table, is to say that the child comes equipped with biases that help narrow the possible referents and support forming a mapping. An alternative response, however, comes from a focus on the multiple individual tasks the child must do to create the new mapping; they must segment the word-form from the speech stream, encode that word form, find the referent, encode the critical features of that object, create a mapping between the word-form and referent, and build a representation of the new word-object mapping strong enough to be integrated in the growing vocabulary. Each of these sub-tasks can be argued to draw on different general cognitive abilities, statistical learning, memory encoding, attention, association, and storage into long-term memory. Recent work in the field has argued and supported the role of these more general processes in word learning and vocabulary growth. Here, we focus on two processes at the heart of referent mapping and learning: attentional processes that support finding referents and memory processes that support building robust word-object mappings.

1.4 Attentional processes that focus processing on the referent and its features

To make a new mapping between a word and an object, children must attend to the object; this will help to form a representation of the object, which will be the target for the new word-object mapping. One form of attention seen in caregiver–infant social interactions that influences word learning is joint attention. Joint attention refers to the simultaneous, joint fixation by caregivers and infants on the same object. It occurs for varying amounts of time, in between attentional switches between various objects by each party (Abney, Suanda, Smith, & Yu, 2020; Yu et al., 2019). Coordinated attention with caregivers is crucial for infants, as it helps them understand goals and intentions (Charman et al., 2000) and supports word learning (Yu & Smith, 2016) by creating opportunities for 'word–object' mappings necessary for acquiring new vocabulary (Baldwin & Markman, 1989; Mundy et al., 2007). For example, joint attention aids word learning by focusing infants' attention on a mutual object of interest (Yu & Smith, 2016; Yu et al., 2019). One study of parent–child interactions that examined parent–infant coordinated attention during free-flowing interactions found an association between coordinated attention and vocabulary size at 12 and 15 months (Abney et al., 2020). During these interactions, if a parent effectively draws an infant's attention to an object while naming it, the infant not only learns to associate the word with the object but also enhances their attentional skills, which are vital for learning additional words. This effective use of coordinated attention as a conduit for language acquisition points towards the importance of understanding the nuances of these interactions.

A growing number of studies have shown that children look longer at a target object when it is named and are more likely to remember the name–object mapping than when visual attention to the named target is longer (MacRoy-Higgins & Montemarano, 2016; Pereira, Smith, & Yu, 2014; Salley, Panneton, & Colombo, 2013). It demonstrates that joint attention and sustained attention, usually measured separately, typically are associated. Specifically, infant visual attention to an object lasts longer when it occurs within an episode of shared attention (Yu et al., 2019; Yu & Smith, 2016). This is documented in the studies by Yu and Smith (2016) and Yu et al. (2019), which highlight that an infant not only focuses on an object but maintains that focus longer when the caregiver actively shares the focus, engaging with the object and the infant simultaneously. This shared engagement helps to anchor the infant's attention, making the interaction a more potent moment for learning and reinforcing the association between objects and their respective names.

Thus, according to Yu et al. (2019), it is also sustained attention, not just joint attention that is critical. Their research highlights that both joint attention and sustained attention predict vocabulary at 12 and 15 months but infants' sustained attention in the context of joint attention, not joint attention itself, is the stronger unique predictor of later vocabulary size. To examine this issue, Yu et al. (2019) employed dual head-mounted eye tracking to capture momentary gaze data from both parents and infants during toy-play sessions. Sequential patterns extracted from continuous gaze streams showed that infants who could maintain sustained attention to objects named by their parents later had larger vocabulary. The results suggest that while joint attention facilitates the context for learning, it is the infant's sustained attention that is essential for robust word–object mappings and subsequent vocabulary growth (Yu et al., 2019). This finding aligns with previous studies, which indicate that sustained visual attention allows infants to form stronger and more enduring representations of word–object pairs (Reynolds, 2015). Thus, enhancing environments to foster sustained attention could significantly impact early language acquisition and long-term linguistic development.

Another form of attention suggested to support word learning is embodied attention. Yu and Smith (2012) suggest that toddlers learn words more effectively when they physically interact with objects. This physical engagement not only captures the child's attention to the presented object but also reinforces memory and understanding of the word associated with the object. To illustrate this, Yu and Smith (2012), explored the impact of direct interaction with objects on vocabulary acquisition in toddlers. They provided one group of children the opportunity to handle objects while learning new words, whereas a control group observed the same objects without direct interaction. The results showed that the group with physical interaction had a higher retention rate of the words, indicating a deeper encoding of the word-object associations. This research underscores the importance of active tactile engagement in enhancing early language learning, suggesting that such embodied experiences can significantly bolster the connection between new words and their meanings.

Relatedly, Yoshida and Fausey (2018) suggest that how an object is presented and how a child interacts with its objects significantly influence how children form lexical representations. They review research investigating how infants engage with visual objects in their environment to enhance language learning. They detailed that infants first need to locate and focus on objects within complex and often cluttered scenes, where objects may overlap or be partially hidden. Their review reveals that frequent and varied encounters with objects in dynamic and engaging contexts enhance children's ability to form and retain word–object associations. They show that children exposed to objects through feature rich visual contexts demonstrate improved vocabulary development. This enhancement was attributed to the enriched visual stimuli that facilitated the encoding and consolidation of memory, leading to more robust mental representations of words.

Finally, attention could also be said to be related to vocabulary development in the context of word learning biases such as a bias to novel objects and the shape bias. As described above, the novelty bias operates by directing attentional resources towards new information and, by some accounts, is the basis for mutual exclusivity (Mather, 2013; Mather & Plunkett, 2012, 2011). Thus, these word learning biases are arguably operations of the attentional system. Likewise, one account of the shape bias suggests it is a learned attentional bias. Smith et al. (2002) propose that the mechanism behind shape bias involves training children's attention to the most critical features of common nominal categories to quickly learn new words. As children acquire vocabulary, they develop the ability to focus attention on relevant information and ignore distractions, which helps them efficiently connect words to objects and foster their vocabulary development. This happens as the naming context common with solid rigid objects—count noun syntax—becomes associated with the most common organising feature for solid rigid things—shape.

As seen in all the research presented in this section, attention is vital for children to learn a mapping between a word and an object. Children must attend to the object; this helps them to form a representation of the object. These findings converge to highlight the importance of selective attention toward relevant information in successful word learning. Attention is also the first step in children's ability to retain the objects and links to words. In particular, work on the shape bias and the idea that it is an attentional bias learned during the course of early vocabulary development supports the idea that attention is a critical underpinning process for vocabulary development. But attending and forming an initial mapping are only the first steps in the word learning process. Full word learning requires integration in the lexicon and use of the word at later points in time. Thus, memory processes are critical to word learning.

1.5 Memory processes that help remember the object and the mapping

After children have found the referent for a novel word, they must encode all components of the mapping so as to be able to retrieve the word-form, referent, and the link between the two at a later point in time. There are multiple memory types involved in encoding associations via 'associative memory', the building of 'conceptual' representations, and the ongoing maintenance of new lexical information, which all intersect to shape early vocabulary development. Each process contributes uniquely to how children learn and use new words. Memory for associations helps with initial learning, and it helps to anchor new words in the child's memory by linking them to their corresponding objects or concepts. Following, conceptual memory then extends beyond the initial simple association, aiding children in understanding and categorising the referents of words within broader contexts and conceptual frameworks. As conceptual memory improves, children can better assign objects to categories and leverage this knowledge to reason about new exemplars (Forsberg, Guitard, Adams, Pattanakul, & Cowan, 2021). This is because conceptual learning builds on the idea that things are organised into categories. Lastly, working memory is essential for the temporary storage and retrieval of word labels, or the recently seen objects that might be the referents of those labels. Working memory then allows children to recall and use new words actively in conversation or thought (Forsberg, Adams, & Cowan, 2023), and might also be critical in creating new mappings. Together, these memory processes, working memory, memory for associations, and conceptual memory, interact dynamically to support a child's ability to not only learn but also efficiently utilise new vocabulary in their developing language repertoire.

1.6 Working memory in word learning

Working memory, or the temporary storage of information for processing or use, is relevant to both the auditory and visual side of early word learning. On the auditory side working memory is critical for the initial encoding of new word-forms, particularly as the speech stream occurs in a linear fashion and is fleeting. Thus, to begin to learn the word "banana" when mum presents the new food at mealtime, the child must encode the components of the word in working memory to make a representation that can be mapped to a referent. On the visual side, working memory may also facilitate noun learning by temporarily holding a representation of recently viewed objects that could be the target referent of a new word. For example, upon hearing "try the banana" at mealtime, the child might use memory that a new item was just added to the plate to help identify the referent of the new word "banana". And working memory can also be argued to be implicated in the maintenance of newly-formed word-object mappings or in retrieving a label to participate in the conversation (Forsberg et al., 2021).

A large body of research has examined the behavioural and neural bases of phonological and verbal working memory, which are closely linked to word learning (for a review, see, e.g. Acheson & MacDonald, 2009). Verbal working memory refers to the temporary maintenance and manipulation of verbal information (Baddeley, 1986) and relies on a sound (phonological) system. Ellis (1980) noted that errors on verbal working memory tests parallel those that occur naturally in speech production after systematically exploring links between constraints on the error in verbal working memory together with language production. According to the review by Acheson and MacDonald (2009), verbal working memory tasks are closely linked to the mechanisms underlying language production, particularly in the serial ordering of verbal information. They emphasise that phonological encoding – the process by which speech sounds are organised for articulation – plays a crucial role in maintaining and recalling verbal information. This connection is evident in the similarities between errors made in verbal memory tasks and those in natural speech production, both of which are subject to constraints, such as phonological similarity and positional errors. Their review suggests that the same processes that manage serial ordering in language production are involved in verbal working memory, with long-term linguistic knowledge, such as familiarity with words and phonetic patterns, influencing performance in both domains. However, while many memory errors can be attributed to these production-based mechanisms, Acheson and MacDonald (2009) also acknowledge that certain errors, such as omissions, may arise from higher-level planning processes, indicating that the relations between memory and language production is multifaceted.

Weill (2011) found that the phonological system, a key component of verbal working memory, plays a crucial role in toddlers' ability to rapidly acquire new words. The phonological loop is responsible for temporarily storing and processing unfamiliar sound sequences, such as new words, which is essential for early language development. In Weill's study, toddlers aged 24-30 months with greater phonological loop capacity were more successful at learning new words, indicating a strong positive correlation between phonological memory and vocabulary size. Notably, the phonological loop was a stronger predictor of word-learning ability than the toddlers' existing vocabulary. This research highlights the importance of phonological memory in early language acquisition.

According to Jackson, Leitão, Claessen, and Boyes (2021), children with developmental language disorder (DLD) face significant difficulties in word learning, particularly in encoding and re-encoding novel word forms and meanings. In a period of a four-day protocol, children were taught eight novel words; in day one, they measured their encoding; in days 2 and 3 they measured re-encoding; and on the last day, day four, they assessed retention. Word learning success was evaluated using Naming, Recognition, Description, and Identification tasks each day. They found that children with DLD showed similar performance to the TD group on the Identification task, showing an ability to learn the form-referent links. In contrast, children with DLD performed worse for Naming and Recognition (signifying an impaired ability to learn novel word forms), and for Description, indicating problems establishing new word meanings. These difficulties experienced by the DLD group were apparent on Days 1, 2, and 3 of testing, indicating impairments with initial encoding and re-encoding, though the DLD and TD groups showed a similar rate of learning. The retention assessments on Day 4 were found to be difficult by all the children, and there were no group differences. Lastly, verbal working memory emerged as a moderator of performance on the Naming and Recognition tasks, so children with DLD and poor verbal working memory had poorer levels of accuracy. The study highlights that poor verbal working memory exacerbates the difficulties associated with naming and recognising new word forms, as well as describing word meanings in children with DLD. This underscores the importance of assessing both word learning and VWM when working with children with DLD, as deficits in these areas can significantly hinder vocabulary development. Archibald (2017) argued that phonological WM is fundamental to language learning, especially for children with speech, language, and communication needs, such as those with Specific Language Impairment (SLI). This review focused on phonological working memory as it argues that phonological working memory is the first to be used while children build their vocabulary to use lexical representation and working memory. Children with SLI often struggle with deficits in phonological WM, which limits their ability to learn new words.

Archibald (2017) explores the complex, reciprocal relation between WM and language processing, noting that limitations in WM can reduce the amount of linguistic detail encoded, while poor language skills place greater demands on WM. The review also points out distinct impairments in WM and language abilities in different children, emphasising the need for tailored clinical assessments and interventions that address both WM and language-processing deficits.

As is evident, auditory WM may be important for early language development, especially vocabulary (Ebert & Kohnert, 2009). However, it is not just auditory WM – there is some indication that visual or visuospatial WM also plays a role. Visual WM holds a representation of a visual object while processing associated labels, allowing them to be paired. Visual spatial working memory, a representation of an object's spatial location while processing related information, allows one to temporarily store and mentally manipulate visual information (McAfoose & Baune, 2009). Petruccelli, Bavin, and Bretherton (2012) identified distinct differences in the working memory (WM) capacities of children with SLI compared to resolved late talkers and typically developing children. Children completed subtests from the Working Memory Test Battery for Children, specifically the digit recall and word list recall. They also completed nonword repetition and recalling sentence tasks to examine the components of Baddeley's working memory model, which is part of the Children's Memory Scale. Petruccelli et al. (2012) findings showed that children with SLI exhibited significant deficits in both verbal and visuospatial WM tasks at five years of age. This impairment was particularly evident in tasks requiring the storage and manipulation of phonological information. Resolved late talkers, on the other hand, demonstrated WM profiles more similar to those of their typically developing peers, suggesting that their earlier delays did not result in long-term WM deficits. In terms of visual working memory, the argument is that it can enable interactions between word knowledge and visual processes. For example,Vales and Smith (2015) suggested that visual search is guided by WM representations. They found that visual WM naturally prioritises visual attention to items in the array that match the contents already in visual WM.

And there may be developmental changes in how these processes relate to language development. Hitch, Woodin, and Baker (1989) argued that there is a developmental shift towards greater reliance on phonological memory as children age. Hitch et al. (1989) found that younger children primarily use visual memory to recall objects, whereas older children increasingly depend on phonological coding, as shown by the disruption caused by phonemic similarity in recall tasks. However, when phonological strategies were blocked using articulatory suppression, older children relied on visual memory, suggesting that visual WM remains active but is typically overshadowed by phonological processing. This research indicates that, although phonological memory becomes dominant with development, visual WM continues to play a role, particularly when phonological resources are unavailable (see also, Farabolini, Ceravolo, & Marini, 2023). The findings support a dual-coding model of WM, where both visual and phonological systems operate in parallel, with their roles evolving throughout cognitive development.

Pickering, Peters, and Crewther's (2023) meta-review of the role of visual memory in vocabulary development further supports findings from multiple studies, emphasising how visual working memory not only supports the acquisition of new vocabulary but also enhances the retention and recall of learned words. Pickering et al. (2023) review findings that individuals with stronger visual memory skills tend to have a richer and more expansive vocabulary. This correlation suggests that visual memory may serve as a crucial cognitive tool in language development, helping individuals to better encode, store, and retrieve linguistic information. They found that enhanced visual working memory capacities are linked to more robust language skills across different age groups. This is particularly relevant in studies focusing on late talkers, where deficits in working memory often correlate with slower vocabulary development. These insights demonstrate the need to consider visual working memory in studies of word learning, as it enables children to effectively pair objects with corresponding labels and supports overall vocabulary growth.

1.7 Memory for associations

This type of memory involves the ability to form and recall connections between different stimuli, such as words and their meanings or objects and their names. Various studies have evaluated associative memory in children after no delay or a small delay (Hay, Pelucchi, Estes, & Saffran, 2011; Ngo, Newcombe, & Olson, 2018; Sluzenski, Newcombe, & Kovacs, 2006) or even 24 hours after learning (Simcock & Hayne, 2003). Memory for associations plays a critical role in forming initial connections between nouns and their referents. It allows children to link words with their corresponding objects or concepts. For instance, when a child learns the word “cup”, memory for associations helps them maintain and remember the association.

Knabe and Vlach (2023) investigated children’s attention to and memory for associations between words, objects, people, and wider environmental contexts encountered during a word learning episode. Their study included a learning and a testing phase. In the learning phase, children viewed animated videos, and in the testing phase, they were presented with six forced-choice recognition tests for six categories of associations: word-object, person-object, scene-object, scene-person, scene-word, and person-word associations. They found that children have strong association for the word learning context, specifically person and scene context. However, they revealed that children generally use this to map words and objects. This shows that children build context-based associative matrices to aid in word mapping, suggesting that researchers should prioritise contextual information in the development of word learning theories. This study shows how various cues provide the opportunity for children to generate many associations, such as between words, objects, people, and the broader environmental context.

A study by Vlach and Johnson (2013), examined how children’s developing memory abilities support learning in a CSWL task by manipulating how many trials elapsed between repeated presentation of the same words. Sixteen- and twenty -month old children participated in a CSWL task, but they experienced a 5-minute delay between learning and testing. In the CSWL task, Vlach and

Johnson (2013) manipulated the presentation timing of the object-label pairings to either massed or interleaved. Results suggest that older children can remember words with more space between individual presentations, while younger children need the words to be presented in a more massed fashion. The implication is that older children's memory processes are more developed, allowing to bridge larger gaps between presentations and supporting learning.

1.8 Memory for objects

Memory for objects plays a crucial role in cognitive development, particularly in how children learn and remember objects that are associated with words. This type of memory involves the ability to recall object features and the contextual details surrounding these objects, which is crucial for language acquisition. One notable study in this area is by Vlach and DeBrock (2017), who explored how memory for objects supports word learning in cross-situational word learning (CSWL) tasks. They used a CSWL task, a language task (the Peabody Picture Vocabulary Test) and a memory task. The memory task involved children being first trained on pairs of pictures presented on a screen. In the following test, children were shown a target picture and two choice options. The experimenter then asked the children to indicate which choice picture went with the target. They found a relation between children's performance on the task and their vocabulary size, children with more vocabulary showed better memory. They also found that performance on memory task, was related to performance on the CSWL task. To the extent that learning words in CSWL requires combining information across separate presentations, this research suggests that the ability to remember objects across individual presentations is important for word learning.

This finding is corroborated by other studies which show that tasks requiring children to recall named objects can lead to improved language outcomes. For instance, when children engage in activities where they need to remember objects that have been explicitly named, they tend to form stronger word-object associations, thereby facilitating the acquisition of new vocabulary (Werker, Cohen, Lloyd, Casasola, & Stager, 1998). Werker et al. (1998)'s investigated the age at which infants can first form word-object pairings with minimal exposure and without the need for social or contextual support. 8 to 14 month old infants were first habituated to two word-object pairings, then presented with one trial that maintained the original pairing and another that introduced a familiar word and object in a new combination. Across six experiments, only the 14-month-old infants successfully formed word-object associations under these controlled conditions, but they did so primarily when the objects were moving. While 8- to 12-month-old infants did not form such associations, the study found evidence that they processed both the word and the object. This research demonstrates that the ability to rapidly learn arbitrary word-object associations develops around 14 months, assessing early word learning in infancy. The study demonstrates a developmental progression from processing words and objects separately to meaningfully, integrating them offering valuable insights into the cognitive foundations of early word learning. Overall it is supported that memory for objects, which could be a strategic focus in early educational interventions, improves children's vocabulary learning during the language learning process.

1.9 Memory and developmental change

Recent work with a computational model of word learning suggests that developmental changes in early word learning may be due to changes in memory. Bhat, Spencer, and Samuelson's (2021) used a dynamic neural field model to examine the processes that support cross-situational word learning in infants, children and adults. Bhat et al.'s (2021) WOLVES, Word Object Learning via Visual Exploration in Space, model autonomously explores the objects presented during CSWL while the words are presented. If it happens to be attending to an object when a word is presented, an association between the word and the attended object features is created. Over time, because the correct words and objects are presented together most often, the model will repeatedly strengthen the associations between the correct words and object features more than other associations such that at the test, it demonstrates learning of mappings, just as children do. To capture developmental change in this ability, Bhat et al. (2021) manipulated a parameter that controls how long word-feature associations take to decay with older children and adults having slower memory decay. Longer decay times mean that an association is more likely to have some remaining strength when it is revived in subsequent presentations, and learning is more robust. Using changes in this parameter, Bhat et al. (2021) were able to capture data from 12 studies of infant, child and adult CSWL, providing the only account of developmental change in CSWL and, thus, a strong argument for memory processes in the vocabulary development.

1.10 The present study

Overall, the literature suggests roles for attention and memory in early word learning and that differences in these abilities may be related to differences in children's vocabulary development. Attentional processes direct young learners to focus selectively on relevant possible referents to linguistic input, thereby facilitating the initial stages of word learning. Memory, especially associative memory, memory for objects, and working memory, support word learning via maintenance of associations between words and objects, representations of objects and temporary storage of new information, all crucial for the active use and later retrieval of newly learned words. Associative memory facilitates the linking of words to their corresponding objects, allowing children to form stable word-object associations, that are essential for vocabulary building. Memory for objects aids in recognising and recalling the physical characteristics of objects, which reinforces word-object connections. Similarly, enhanced associative memory and robust object memory also play critical roles in supporting efficient word learning and retrieval.

However, the concrete relations between attention, memory and word learning are not fully elucidated and remain partially understood. As all these mechanisms play a vital role in children's development of word learning, it is vital to have a study that investigates potential relationships between these. Towards this end, the present thesis presents three experiments with the goal of understanding the roles of attention and memory in children's acquisition of words, which form the basis of early language development. Chapter 2, the first empirical chapter focuses on attentional processes by taking a deeper look at the idea that shape bias is an attentional bias. Intensive coding of infants' looking behaviour during noun generalisation task is used to ask whether attention to shape is directly cued when objects are named. The study suggests this is the case, but only for children who have already learned a good-sized vocabulary. Chapter 3, the second empirical chapter focuses on the relation between children's object memory and vocabulary development. It explores whether developmental changes in object memory are connected to vocabulary growth in children between 14 and 27 months of age. Findings indicate that strong object memory is linked to more advanced vocabulary development during this period. Finally, Chapter 4, the last empirical chapter, describes a multi-session study that brings together the tasks and issues from the prior two empirical studies. Children between 18 and 26 months of age completed the novel noun generalisation and object memory tasks from the prior chapters, and their vocabulary was measured. In addition, we measured their long-term memory of the novel names presented in the noun generalisation task and their working memory. Data from each of these measures in turn are presented but also examined relations between working, object and long-term memory and attention in the noun generalisation task. Chapter 5 incorporates the findings from the previous chapters and discusses their contribution to our understanding of the role of memory and attention in children's vocabulary development. Limitations and future directions of this work are also discussed.

Chapter 2

The relation between novel words and gaze dynamics in noun generalisation

2.1 Introduction

Words direct attention. As infants, children, and adults hear words their gaze is directed to things in the world that match the words they hear. This phenomenon is the target of increasing amounts of research elucidating the relation between language and visual perception (Bobb, Huettig, & Mani, 2016; Carvalho, Vales, Fausey, & Smith, 2018) and the mechanisms that support early word learning (Vales & Smith, 2018). It is also the basis of preferential looking tests of early word and language learning, including speed of processing tests using known words (Fernald & Marchman, 2012) and comprehension tests with likely-to-be-known words (Friend & Keplinger, 2003). Presentation of the word presumably activates a representation of the known or newly learned referent, that then directs attention to the corresponding visual realisation. Looking at a visual stimulus then, provides evidence that children know a particular word (e.g., Friend & Keplinger, 2003).

Previous research has found a link between an infant's visual attention to objects and categories and early word learning. For example, research examining dyadic interactions between parents and infants has demonstrated that if parents support greater attention to objects it leads to more object generalisation (Yu et al., 2019). Also, Yu et al. (2019) found that sustained attention to objects demonstrated in children enhances word learning and predicts later vocabulary size.

There is also clear evidence that more abstract aspects of language itself, beyond known word-object mappings, can guide toddler's attention such that the presence of language can cue attention to meaningful visual information, even in the case of novel, unknown words. Presenting a novel word during familiarisation trials introducing a category increases the time infants spend looking at stimuli (e.g., Haaf et al., 2003). Similarly, Carvalho et al. (2018) found that specific words in children's vocabulary affect and guide their visual attention. Carvalho et al. (2018), investigated to what extent children's visual information seeking is affected when infants hear a sentence with a novel name versus without a novel name. Using an eye tracker, the researchers watched children's moment-to-moment eye movements while completing a match-to-sample task. They found that the inclusion of novel names changed how infants sampled the presented stimuli. Novel words extended the duration of the sampling event without affecting where children looked or the transitions between objects and words (Carvalho et al., 2018).

Novel words also influence the specific gaze targets within stimuli—directing gaze to shared object features, (e.g., Althaus & Mareschal, 2014). In such studies, novel words are often presented in sentence frames (e.g., "Look at the blicket!”), suggesting that the ability of novel words to cue attention is based in part on acquired knowledge of similar naming events. One case in which this claim has been made directly is the shape bias.

2.1.1 The Shape Bias

The shape bias refers to the tendency to generalise novel names for novel objects according to similarity in shape. It is an attentional and word-learning bias (Landau, Smith, & Jones, 1988). It is commonly measured in novel noun generalisation (NNG) tasks with 3-dimensional objects that children can manually explore and are asked to hand over to the experimenter when prompted with a novel name. For example, Samuelson and Smith (1999), gave 17- to 31-month-olds an exemplar and two test objects, a shape-only match, and a material-only match, to explore. The objects were then retrieved, the exemplar held up, and a novel name provided, e.g., “Look! This is my zup,”. The child was then asked to generalise the novel name, e.g., “Can you get your zup?”. The common finding in this and other studies, is that from around 2 years of age, children pick the shape-matching test object as the generalisation target. Subsequent studies have confirmed this tendency (Samuelson & Smith, 2000; Smith et al., 2002; Diesendruck & Bloom, 2003).

The shape bias has received much interest in the 30 years since Landau et al. (1988) initial demonstration because it necessarily requires application of knowledge beyond that of the novel word presented and is an example of few-shot learning not yet rivalled by the best computer vision models (Ritter, Barrett, Santoro, & Botvinick, 2017; Smith & Slone, 2017; Sung, Yang, Zhang, Torr, & Hospedales, 2018). While the shape bias is robust and has been found to be reliable in predicting future vocabulary growth (Smith et al., 2002), children’s performance in the task has also been shown to be influenced by differences in the specific task presented to children (for review see Kucker et al., 2019). These differences are likely to be in part due to the differences in individual children's attention span, familiarity with the task context, and their prior vocabulary knowledge. Thus, the NNG task provides an opportunity to examine how the direction of attention by novel names differs across children as well as the nature of the shape bias.

Of the multiple proposals regarding the nature of the bias and where it comes from (see Samuelson & Horst, 2008), one is that it is based on knowledge of conceptual categories. Children generalise by shape similarity because shape is often relevant to the kind of thing an object is. By this account, the shape bias stems from children's early understanding of linguistic categories and conceptual structure (Diesendruck & Bloom, 2003; Booth & Waxman, 2008; Markson, Diesendruck, & Bloom, 2008). Diesendruck and Bloom (2003) argue that children's understanding of shape is a strong indicator of object kind, as reflected in their shape bias. Their findings indicate that children's reliance on shape intensifies during name extension tasks, implying that the wording of instructions may significantly influence the shape bias. Abdelaziz, Kover, Wagner, and Naigles (2018) used data from studies by Potrzeba, Fein, and Naigles (2015) and Tek, Jaffery, Fein, and Naigles (2008), where children completed the Intermodal Preferential Looking (IPL) assessment of the shape bias at the beginning of each home visit. In this task children were shown unfamiliar object paired with a novel label, then asked to extend the label by choosing between two objects: one with the same shape but different colour, and another with the same colour but different shape. Before these name trials, children "no-name" trials where they were simply asked, "Which one looks the same?" without any labels, to observe their natural grouping preferences. The preliminary results suggest a shape bias–object kind linkage as seen from the behaviour in the classic categorical task. Those who performed more consistently at age 5 years had demonstrated stronger shape bias performance 2.5 years earlier. Davidson, Rainey, Vanegas, and Hilvert (2018) further support this view, demonstrating that the shape bias can be attributed to non-lexical cues, with shape serving as a reliable indicator of an object's category. The "shape-as-cue" account recognises that shape is an imperfect cue for object categorisation, suggesting that children's early conceptual knowledge underpins their shape bias. However, they also argue that the shape bias is particularly relevant to words in early development, evolving as children reach 2.5 years old. At this point the bias becomes more generally applicable.

Similarly, Booth and Waxman (2008) argue that children's preference for generalising by shape similarity is rooted in their early understanding of linguistic categories and conceptual structures. That is, shape as a perceptual property tends to be a reliable cue for category membership since it co-varies with the function and identity of objects. Booth and Waxman (2008) argue that the shape bias can be influenced by linguistic information related to animacy. They also suggest that toddlers in the early stages of word production exhibit a shape bias. For example, Booth, Waxman, and Huang (2005) found that even young children who have fewer than 50 count nouns in their vocabularies have the tendency to generalise a novel name based on shape similarity. From these results, they advocate that the shape bias is based on conceptual knowledge that does not develop from early vocabulary learning, but is instead a manifestation of children's innate understanding of the structure of reality. It is for this reason, that in some tasks, infants display this bias in general induction tasks requiring them to generalise non-obvious object properties (Booth et al., 2005; Graham & Diesendruck, 2010). Graham and

Diesendruck (2010) investigated how infants prioritise shape over other perceptual properties in an induction task, with the goal of further elucidating the mechanisms behind category formation and word learning. Their study found that 15-month-old infants were significantly more likely to generalise a non-obvious property to novel objects that shared shape similarities with a target object, rather than to objects that shared colour or texture. These views are further reinforced by Booth and Waxman (2008) and Markson et al. (2008), who argue that shape serves as a critical cue, guiding children's categorisation processes from a very young age due to its relevance to the objects' functional and categorical identity. When objects within the same category have dissimilar shapes, preschoolers demonstrate sensitivity to conceptual information such as animacy (Booth & Waxman, 2008) or causal origins (Diesendruck & Bloom, 2003). Markson et al. (2008) further support the idea that shape bias arises from the processes of categorisation and understanding the world. They argue that cognitive processes, such as categorisation and language, are interconnected and that shape bias is not a standalone concept. This aligns with the perspective that shape bias is related to the conceptual knowledge engaged during word learning, although it is not exclusively tied to it. Further Booth and Waxman (2008) advocate that this bias is not an outcome of language development

A related idea is that young children demonstrate sensitivity to the referential intent of an object's creator or name. This suggests that objects intentionally made or named are more likely to be linked to shape extension than those created or named accidentally or incidentally (Diesendruck & Bloom, 2003; Gelman et al., 1998; Keates & Graham, 2008; Markson et al., 2008). The study by Keates and Graham (2008), explored how 16-month-old infants generalised properties to objects based on different labelling conditions. The infants were presented with novel objects and labels, such as count nouns embedded within naming phrases (e.g., “This is a blick”). The researchers found that infants were more likely to extend the properties to objects with similar shapes when the labels were presented referentially and marked as count nouns, compared to labels used incidentally or with no specific naming phrase. This suggests that infants rely on intentional labelling to guide their inductive reasoning, showing a preference for labels that denote category membership.

Another proposal regarding the nature of the shape bias, suggested first by Landau et al. (1988) and subsequently by Colunga and Smith (2008) and by Samuelson and Horst (2007), is that the bias is a developmental outcome of children’s acquisition of a language that includes regularities between category organisation, perceptual properties of referents and linguistic features in the early noun vocabulary. This means that as children learn their first words, they are not just memorising labels for objects but are also learning patterns in how words are used. These patterns help them group objects into categories based on shared perceptual features and understand the typical linguistic markers associated with these categories, thereby facilitating more efficient word learning and category formation. Thus, this proposal suggests the bias is related to the developing vocabulary with a prior history of object name learning to training automatic attention to shape similarity when novel solid objects are named (Kucker et al., 2019; Samuelson, 2002; Smith et al., 2002).

Over 30 years of research on shape bias has produced a clear theoretical framework linking development of the bias to statistical regularities in the early noun vocabulary (Perry & Samuelson, 2011; Samuelson, 2002). In particular, Smith et al. (2002), proposed that the shape bias is the learned product of the early noun vocabulary. Nouns are acquired much earlier by children compared to other syntactic categories as they are easier and more accessible (Gentner, 1982; Sandhofer & Smith, 1999; Braginsky, Yurovsky, Marchman, & Frank, 2019). The majority of nouns that young children learn represent concrete things, such as objects seen in their everyday life, a “cup”, a “ball” and “banana” as these dominate the speech they hear. Further, of the nouns naming concrete objects, many label solid objects in categories that adults suggest are well organised by similarity in shape (Gershkoff-Stowe & Smith, 2004; Samuelson & Smith, 1999; Perry & Samuelson, 2011). Such nouns may be learned earlier by infants, because object shapes are one of the easiest visual elements to identify, particularly in young children whose brains and senses are still developing (Smith et al., 2002). Other object properties, such as texture or material, are sometimes unnoticeable at first, requiring closer examination, while shapes are more obvious even though they are visually complex (Landau, Smith, & Jones, 1992).

Previous studies provide evidence that the early noun vocabulary contains many names for solid objects in categories well organised by shape. Samuelson and Smith (1999) found a relations between noun knowledge and object generalisation, with the latter not occurring without significant amounts of the former. Children between 17 and 32 months old completed a NNG task, and the child’s vocabulary count was collected via the MacArthur–Bates Communication Development Inventory (MCDI) (Fenson et al., 1994). The MCDI has been used as a measure of vocabulary development in research for the past years (Mayor & Plunkett, 2011). Samuelson’s (1999) research suggested that shape bias would be helpful, as the majority of the 300 nouns children had acquired in their vocabulary development were organised by shape similarity. They also found that children exhibited shape bias only when they had 150 nouns in their productive vocabulary. Samuelson and Smith (2000) also found similar results suggesting the early noun vocabulary was biased to include more names for rigid objects that are similar in shape.

Similarly, Gershkoff-Stowe and Smith (2004) conducted longitudinal research examining children's attention to shape using parental diaries, where they would record any new words learnt by the children as well as visits to the lab every 3 weeks for the NNG task for a minimum of 3 and a maximum of 6 months period. They measured vocabulary weekly and found that it wasn't until children had 50 nouns or more in their productive vocabulary, that they showed shape bias in a discrete choice NNG behaviour task.

The idea then, is that when children hear the count noun syntactic frame it directs their attention to the object's shape. Count nouns provide strong associations with shape-based categories that can guide language learning progresses (Samuelson, 2002; Colunga & Smith, 2008). Thus, as children learn more names for objects organised into categories by similarity in shape, they become more attentive to shape when presented with new words to learn (Smith et al., 2002). This "attentional learning account" of the shape bias (ALA, Smith, 2001) is a theoretical proposal explaining that children learn associations between linguistic cues and attention to particular objects' features and that these learned associations drive attention automatically to the relevant properties of objects by the context of a naming task (Colunga & Smith, 2008).

The strongest support for the ALA comes from studies by Smith et al. (2002) and Samuelson (2002) demonstrating that children's shape bias can be trained. Smith et al. (2002) trained children who did not yet show a shape bias in the NNG task by teaching them object names for novel categories perfectly organised by similarity in shape. The children who were trained, showed a precocious shape bias and an increase in their acquisition of new words. Likewise, Samuelson (2002) taught children names for categories the children did not yet know, but that are typically learned before 26-months-of age. She found, using two longitudinal studies, that children trained on a set of categories that represented the typical statistical distribution of the early noun vocabulary (more names for solid things and categories organised by shape), but not children trained with categories organised by material similarity, developed an early shape bias. The children trained on a set of words that matched the typical distribution of the early noun vocabulary also showed an acceleration in their vocabulary development. Interestingly, however, these children overgeneralised the shape bias to the naming of non-solid objects.

The ALA is also supported by work using computer model simulations. According to Samuelson's (2002) neural network simulations, when a neural network was trained with a vocabulary that matched the statistics of the early noun vocabulary, it became biased to generalise material for non-solid substances and shape for solid objects. This suggests that the statistics of the vocabulary are sufficient to produce the shape bias in a simple associative learner, but also provides a contrast to Samuelson's (2002) data from children trained with the same statistics. Later simulations by Colunga and Smith (2005) further examined how statistics in the vocabulary relate to the shape and material biases and the probed the features of objects and that could lead to a bias to generalise novel names for nonsolid substances by material similarity.

These simulations showed that general learning processes are able to create generalised distinction between solids and non-solids. The researchers found that learning was crucial in distinguishing solids from non-solids, preventing them from being mistakenly identified as belonging to the same category. This distinction was also observed in tasks performed by children, who integrate linguistic input and perceptual experiences to form distinct categories, highlighting the role of learned associations in shaping early cognitive development. This also accounts for why the networks were found to be context sensitive. Overall, the researchers concluded that children perceive solids and non-solids in fundamentally different ways.

In conclusion, there are two accounts that explain shape bias. The first suggests that shape bias emerges from children's understanding of categories and conceptual structures. The second, ALA, suggests that shape bias emerges as children's attentional system is gradually tuned to the relevant properties of objects within the context of a naming task as their vocabulary grows. It is interesting to note that the data seem to support both accounts depending on how they are interpreted (Elman, 2008). The ALA provides an explanation for how children develop a shape bias during learning, primarily due to linguistic experience. Children learn the categorisation of shape as a relevant dimension in the system through the linguistic experience, where attention to shape when categorising objects is useful in determining an object's kind (Samuelson & Horst, 2008). One of the advantages of the ALA provides an explanation for how children develop a shape bias during learning, primarily due to linguistic experience. Another, strength is that ALA argues that that attention is not merely a passive process but is actively shaped by associative learning, where children learn to connect words with object properties and perceptual categories Keil (2008). This framework effectively explains how children as young as two years exhibit a well-documented shape bias, systematically focusing on different properties for different types of objects like the shape for artifacts or material for substances.

Despite its strengths, the ALA faces critiques regarding its scope and the mechanisms it proposes. Critics such as Cimpian and Markman (2005) and Booth et al. (2005) argue that the shape bias may not be as pervasive or fundamental as the ALA suggests, proposing that conceptual knowledge, rather than attentional learning, drives this bias. These critics highlight that the ALA may overlook other general cognitive abilities that children bring to the development of the shape bias, including prior knowledge of categorisation (Elman, 2008). In this sense, while the ALA offers important insights into how word learning proceeds, it may need to be considered alongside other accounts that emphasise the role of conceptual understanding in cognitive development. Additionally, the ALA has been criticised for not fully accounting for the early onset of shape bias or for shape bias in non-syntactic contexts Keil (2008). In this sense, the ALA offers important suggestions about how word learning proceeds. However, it may be necessary to state that it fits in alongside other accounts that stress the importance of conception in cognitive development.

Overall, these critiques highlight a need to investigate the interplay between conceptual and perceptual learning in shaping children's linguistic and cognitive development. The current work seeks to contribute to a better understanding of the link between vocabulary and attention to shape in novel noun generalisation tasks by more directly measuring how naming events cue attention to shape. One issue with the proposal in the ALA is that the presentation of a novel word directly cues attention to shape and that supporting evidence comes from children's final selections in the noun generalisation task. It is possible in this case, that rather than words directly cueing attention to shape, children may have spent some amount of time comparing the possible referents or engaging other more deliberative processes in the time between word presentation and the generalisation decision. Thus, it could be argued that the NNG task does not measure attention directly, moment-by-moment as the task unfolds. But if names direct attention to shape, it should be reflected in children's attentional behaviours to the objects presented in the task before the final generalisation response.

Further, while there is robust evidence linking the development of the shape bias to the development of the vocabulary, other works suggest that this link is not direct. For example, there are disagreements between studies in the number of nouns a child needs to learn before they demonstrate a shape bias. Gershkoff-Stowe and Smith (2004) concluded that 50 nouns are enough for children to display shape bias, whereas Samuelson and Smith (1999)found that 150 are needed for this to occur. Much younger children have been shown to demonstrate shape bias in less demanding tasks (Smith et al., 2002) while linguistic organisation influences attention. Thus, examining whether the naming event of the NNG task itself influences attention to shape, and how this is related to the number of known nouns will provide new data on the mechanism of the shape bias.

2.1.2 The present study

The present study aims to better understand the link between vocabulary and attention and how naming novel solid objects directs children's visual attention to shape similarities. To do this we embedded a looking-while-listening procedure (Fernald, Zangl, Portillo, & Marchman, 2008) within the standard NNG task via close-up video of the toddlers' face and eyes. We coded this video frame-by-frame to determine where toddlers were looking before and after the presentation of the novel noun, but also while they were manipulating the objects. No prior work has looked directly at the visual exploration process that supports children's selections when generalising novel nouns—critical for understanding how language and visual attention interact to support word learning and communication more generally. Thus, we examined the timing of visual attention in the NNG task, asking whether naming drives attention to directly shape or whether more deliberative processes are involved.

We considered three possible hypotheses for the relation between the naming event and children's attention. First, if the novel name cues attention to shape directly, children should look equally to the two test objects before the naming event and quickly to the shape-matching test object after. If instead the name cues a more deliberative comparison process to determine the correct generalisation target, presentation of the name should increase the number of looking transitions between the objects following the name presentation (see Folke, Jacobsen, Fleming, & De Martino, 2017; Leckey et al., 2020). A third possibility, based on demonstrated links between visual object perception, including abstract shape information, and word learning (Smith, 2003), is that children will have a more general bias to attend to the shape of solid objects even before the naming event.

2.2 Methods

2.2.1 Participants

We recruited 66, 17-31-month-old children (38 females, 87.9% white, 6.1% mixed race, 6.1% not specified) from a medium-sized city in the East of the United Kingdom. Data from 26 additional children were excluded because they did not complete two warm-up trials (n=2), became fussy (n=12) or due to recording or software errors (n=12). The study was approved by the local ethics committee and Informed consent was obtained from the parents prior to the experiment. All children received a small prize for participation.

2.2.2 Stimuli and Apparatus

The six familiar objects and four sets of novel objects had been used previously by Samuelson (2002). Each novel object set contained an exemplar, two test objects that matched the exemplar in shape but were different in colour and made from a different material, and two test objects that matched the exemplar in material but were different in shape and colour. Novel objects were made of clay, plaster, Styrofoam, yarn, and plastic mesh and ranged from 6 - 11cm in length, 8-10cm in width and 4-13cm in height. The four novel words were Zup, Fum, Mip, and Kiv (Samuelson & Smith, 1999).

A wooden stage was built to house a GoPro camera that recorded a close-up of the child's face (Figure 2.1). The bottom was 80cm x 33cm x 12.5cm and the camera box that sat on top was 23.5cm x 16.5cm x 29.7cm. A support on each side of the camera box, each 10cm x 10cm x 9cm, held the test objects upright during the naming and selection portion of the trial. Wall-mounted cameras recorded the experimenter and a side view of the table. A digital timer was mounted on the wall behind the child within view of the experimenter.

2.2.3 Procedure

In a waiting room, the parent read an information document and completed the Oxford Communicative Development Inventory (OCDI; Hamilton, Plunkett, & Schafer, 2000) while the experimenter played with the child. In the experimental room, the child sat across a table from the experimenter and the parent behind and to the right of the child (see Figure 2.1). Parents were instructed to interact only to encourage responding as necessary and then to

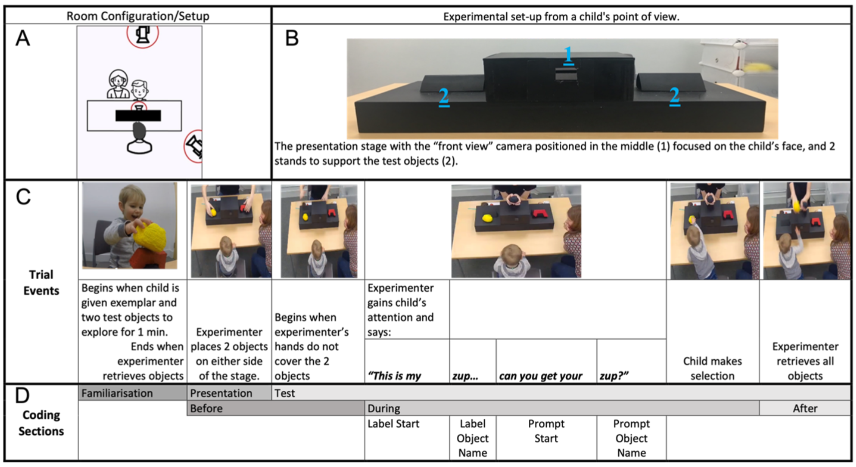

Figure 2.1: Experimental set-up including the room configuration (A) and the view from the child's point of view (B), as well as the sequence of events in a trial (C) and correspondence to coding sections (D).

only use the words used by the experimenter. If necessary, parents finished the OCDI during the study. The child was asked to sit on a chair across a table from the experimenter, close enough to be able to reach the stage (around 50 cm from the table) and the parent in a second chair behind or to the right of the child.

On warm-up trials children were given three familiar objects, two identical and one completely different (e.g., two sheep and a ladybug), to explore for one minute. The experimenter then retrieved all three, put one identical item to one side of the stage, the unique item on the other, held up the second identical item, and said: "This is my (item name), can you get your (item name)." If the child answered correctly, they were praised enthusiastically. If the child did not pick the identical item the experimenter said, "That's not your (item name), this is your (item name)," while pointing to the objects in turn. The child was then encouraged to pick up the correct object before the experimenter started the next trial. The right/left placement of the correct object was counterbalanced across trials. Two correct warm-up responses were required before the experimenter started the novel object trials.

Novel object trials proceeded identically: the experimenter gave the child an exemplar, a shape-match test object and a material-match test object to explore for a minute, touching all the objects to prompt attention to each as necessary. Following this familiarisation, the experimenter placed the test objects on either side of the stage, held the exemplar up, and said for example, “This is my zup; can you get your zup?”, while looking directly into the child’s eyes. When the child responded, the experimenter replied with neutral praise, and removed the objects. If no choice was made within 15 seconds, monitored via the digital timer, two re-prompts, each 15 seconds apart, were given before the experimenter removed the objects and started the next trial. The 16 total trials pitted each shape-match test object against each material-match in a set. Set and trial order and left/right position of objects were counterbalanced across children.

2.2.4 Coding

Behaviour was coded offline, frame-by-fame, by trained assistants using DataVyu (DataVyu Team, 2014). After the experimenter- and side-view videos were synchronised, a first coding pass marked the beginning and end of all trials and broke them into familiarisation, presentation, and test sections (see Figure 2.1). A second coding pass broke the test section of each novel object trial into sections relative to the prompt: before, during and after. “During” was further coded to specify the individual components of the naming event including “Label start,” “Label object name,” “Prompt start,” and “Prompt object name.” The “label start” section included the phrase “This is my.” The “label object name” section was when the novel object name was said. The “prompt start” section was when “Can you get.” And the “prompt object name" section was when the novel object name was said during the prompt. The "label start" section was used to indicate the naming event in analyses.

A third coding pass used GoPro video to code children's looking as right, left, up, or off/not towards objects or camera. Because the exemplar was near the experimenter's face during naming, looks to the experimenter and exemplar could not be distinguished. A fourth coding pass used the side-view camera to determine the child's choice as either the shape-matching test object, the material-matching test object, or no response. A fifth pass used the experimenter-view and GoPro video to code children's touches during familiarisation. When multiple objects were held at once, each object was marked as touched. Coding passes were done in order with different coders coding looking and children's selections. Twenty-five percent of sessions were double coded for reliability with high agreement for all passes: 100% for trial breakdown, 85% for language sections, 92% for looks, and 97% for children's choices. Disagreements were resolved by review of the coding manual and re-coding followed by joint review and discussion of disagreement persisted.

2.2.5 Data Processing

To calculate the proportion of shape and material choices during the NNG task, 48 "no response" trials were removed (5% of the data) from 23 different children with a max of seven trials from a single child. Data from eight of the 66 participants were excluded for failure to complete more than 8 of the 16 total trials, leaving data from 58 children. Additionally, data from three children whose vocabulary development was more than 1.5 standard deviations from the mean for their gender was removed, as children with slower vocabulary development have been shown to perform differently in NNG tasks (Colunga & Sims, 2017; Perry & Kucker, 2019). These data are examined separately, although additional analyses including these outliers revealed a similar overall pattern of results to that reported below with the remaining 55 children. Frame-by-frame looking codes were processed using EyetrackingR (Forbes, Dink, & Ferguson, 2021), which calculated the proportion of looks to the two test objects and "up" and "off" in each 100ms bin.

2.3 Results

We evaluate three hypothesised relations between the naming event in the NNG task and children's attention to shape: the name cues attention directly to shape, the name stimulates a more deliberative comparison process, or that children have a bias to attend to the shape of solid objects that is independent of the naming event. To do so, we examined three aspects of children's visual attention in the task: the time course of gaze dynamics to the exemplar and test objects before and after the naming event, the pattern of looking transitions after the naming event, and differences in attention during the familiarisation period of each trial. We also examined how these behaviours were influenced by productive noun vocabulary size, based on similar relations in prior studies (Samuelson & Smith, 1999).

2.3.1 Overall Shape Responding

We start by asking if this sample of children demonstrated a shape bias in their noun generalisations and whether this was related to vocabulary development. The sample had a mean total productive noun vocabulary of 105.83 words, (*SD*= 67.64 *Median* = 123). The productive noun vocabulary included all words in the animals, vehicles, toys, food and drink, clothing, body parts, furniture and rooms, outside, and household items sections of the OCDI. We

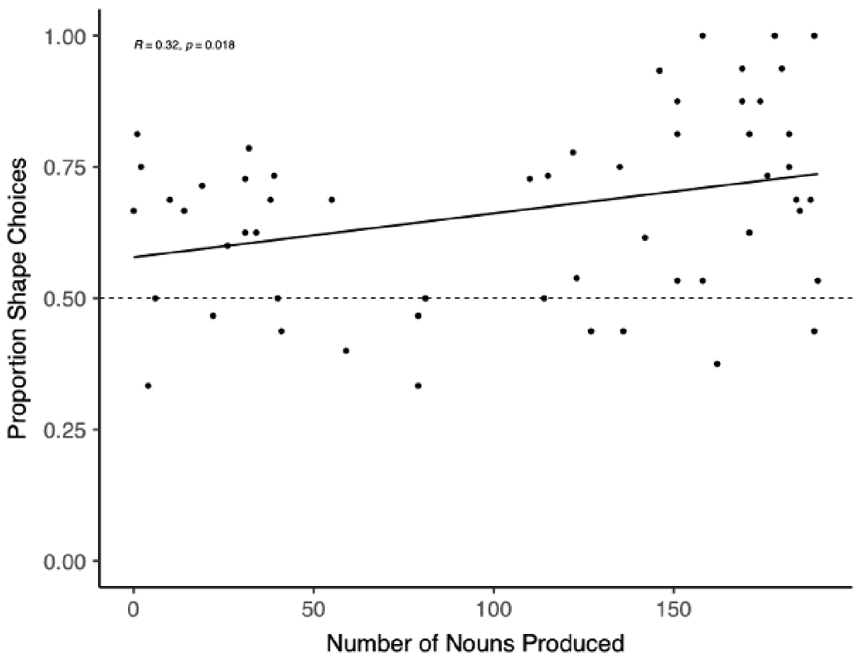

Figure 2.2: Proportion shape responding by productive noun vocabulary size. Solid line represents best fit linear regression. Dashed grey line represents chance level responding (.50).

ran a linear model predicting the proportion of shape choices by a full factorial of noun vocabulary (continuous, centred and scaled), gender, stimulus set, and set order as independent variables. Proportion shape choices was centred by subtracting 0.5 from all scores to enable comparison of the intercept to chance. Stimulus set and set order were not significant predictors and were removed (Table 2.4). The intercept of the final model was significant, t (51) = 7.41, p <.001, suggesting an overall bias to attend to shape when generalising novel names. There was also a significant main effect of vocabulary, t (51) = 2.65, p = .012, (see Figure 2.2) suggesting that, as in prior studies, children's attention to shape was related to the number of nouns in their productive vocabularies. Gender and the interaction of gender and vocabulary were not significant (Table 2.5).

To compare to prior studies, we created Low (93 or fewer, M = 32.3, range

= 0-81, n=32) and High (94 or more, *M* = 158.7, range= 110-190, n=23) noun vocabulary groups using the same proportion of the total nouns on the OCDI as Samuelson and Smith's (1999) 151 dividing point on the MBCDI. The mean age of the two vocabulary groups was significantly different, $t(46.6) = 8.17$, $p < .001$; Low *M* = 624.2 days and High *M* = 757.5, although the ranges overlapped considerably: low 541 - 919 and high 591 – 956 days. The High group made more shape choices, Welch Two Sample $t\ (52.6) = -2.76$, $p = .008$. However, the proportion shape choices was above chance (.50) for both the High, $t\ (22) = 3.20$, $p=.004$, and Low $t(31) = 6.69$, $p < .01$, groups. Thus, like prior studies shape responding was related to vocabulary development, although children with smaller vocabularies also generalised novel names by shape similarity (see also Perry & Kucker, 2019).

In addition to the linear model predicting the proportion of shape choices based on vocabulary groups reported above, we ran a corresponding model with age as the predictor variable. Initial models included a full factorial of age, gender, stimulus set and set order as independent variables. Proportion shape choices was centred by subtracting 0.5 from all scores to enable comparison of the intercept to chance. Stimulus set and set order were not significant predictors and were removed. In the final model there was a marginal main effect of age $t\ (51) = 2.02$, $p = .05$. Akaike's information criterion was slightly lower in the vocabulary model (-35.40) than in the age model (-33.60) suggesting vocabulary provided a better fit.

2.3.2 Looking Time Course

Figure 2.3 shows the time course of looking to the exemplar and test objects before and after the naming event grouped by children's final generalisation selections and vocabulary level. The black line indicates when the novel word

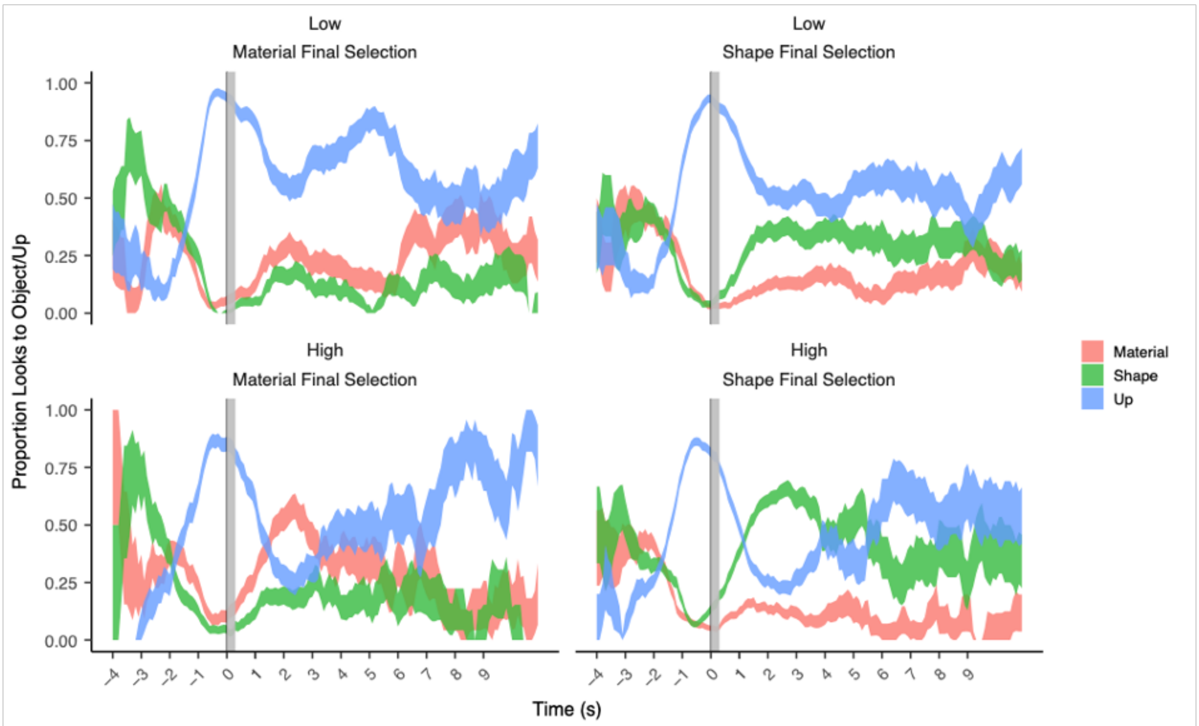

Figure 2.3: Average time course, across sets and trials, of looking to the shape- and material-match test objects and the exemplar for children with Low (<93) and High (>93) productive noun vocabulary groups (see Supplementary Materials for details). Data are grouped by trials ending in selection of the material-match (left) or shape-match (right) test object. Black line indicates the point in the naming event when the novel name was first said. Grey bar indicates beginning of the "after" analysis window. Note that grouping by vocabulary is for visualisation only; vocabulary was a continuous variable in analyses. This figure captures 75% and 93% of trials by the Low and High groups respectively.

was said (the "label start" section of the trial). The "after" analysis window was 300ms from name onset (c.f., Fernald et al., 2008, grey bar) until a generalisation selection was coded. Because children were allowed to respond freely this window varied. It was negatively correlated with vocabulary, R=-0.36, p <.001, thus children with larger vocabularies took less time to generalise the novel noun.

As can be seen, children looked equally to the shape- and material-matching test objects before the naming event and children looked up to the exemplar and experimenter when cued. When the name was said, only children who had more nouns in their productive vocabularies looked to the shape-matching test object then up to the experimenter on the 72% of trials on which they selected the shape-match. These children looked to the material-matching test object before looking to the experimenter on the smaller number of trials ending in a material selection (28%). In contrast, children who said fewer nouns tended to look back and forth between the test objects and the exemplar before selecting, although of the two test objects there appears to be some bias for the object that was eventually selected.

Note that because the trial lengths varied across children, we were unable to run growth curve models on the time course data. Thus, we calculated the proportion looking to the shape-matching test object out of the total looking to the test objects (Figure 2.4) and ran separate generalised linear models with a beta-binomial link function on the before-naming and after-naming data predicting this proportion by the interaction of vocabulary (continuous) and final selection with random intercepts for participants. The model of the before-naming data revealed no significant main effects or interactions, all $|z'| < .50$, $p > .01$. The intercept was also not significant, $z = 0.87$, $p = .39$, suggesting the proportions were not different from chance responding and thus looking to the two test objects was equal before the naming event (Table 2.6).

The model of the after-naming data revealed significant main effects of final selection, $z = 12.02$, $p < .001$ and a significant interaction between vocabulary and final selection, $z = 2.47$, $p = .01$ (Table 2.7). Follow-up models predicting proportion shape responding by vocabulary with random intercepts for participants on the data from trials ending in shape and material selections separately, revealed a significant intercept, $z = 10.60$, $p < .001$, and effect of vocabulary, $z = 2.04$, $p < .05$ for trials ending in shape selections (Ta-

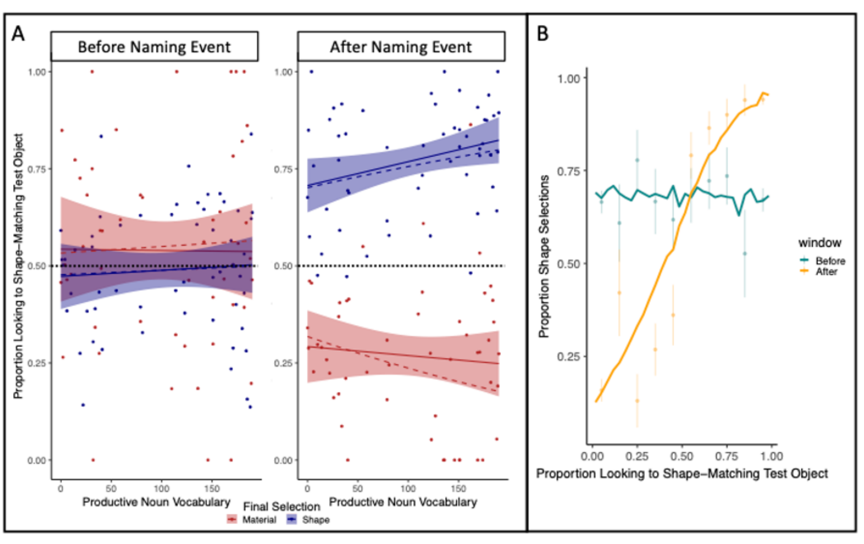

Figure 2.4: (A) Proportion looking to the shape-match test object by productive noun vocabulary size, before and after the naming event. Dashed coloured lines are model predicted data. Dashed black line indicates equal looking to the shape- and material-match test objects (.50). (B) Relation between looking to the shape-match test object before and after the naming event and selections of the shape-matching test object.

ble 2.8), but only a significant intercept, z = -6.80, p <.001 (Table 2.9), for trials ending in material selections. These models suggest that after the naming event children looked to the object they eventually selected and this was related to vocabulary, but only when the name was generalised by shape similarity. Finally, we examined whether looking predicted children's choices (Figure 2.4B). Mixed-effect models with a binomial link predicting children's final selection by proportion looking to the shape-match test object revealed that looking after the naming event, but not before, strongly predicted generalisation, z = 14.50, p <.001 (Table 2.10 & Table 2.11). Together then, the looking time course suggests that the naming event cued attention to the selected object, especially when this was the shape-match test object and when children had more nouns in their productive vocabularies.

As indicated previously, children responded freely during the NNG task, the timing between the experimenter's presentation of the label and children's selections varied. This means that trial lengths were not the same for all children. In particular, children who knew fewer nouns took longer to make generalisation selections: M= 19.45s (Low) and 14.05s (High), Man-Whitney test W=205.5, p <.01. Thus, to confirm that the results reported above held even when these timing differences were accounted for, we created normalised looking time courses before and after the naming event. For the "before" time course we subtracted from each timestamp in a trial the timestamp for the start of the trial and divided by the length of time between the start of the trial and the naming event. For the "after" time course we subtracted from each timestamp in a trial the minimum timestamp following the naming event on that trial and divided by length of the "after" portion of the trial (found by subtracting the minimum timestamp following the naming event from the timestamp corresponding to when the child made a choice as indicated by the off-line coding). We did this for each trial for each participant and averaged over the before and after data separately.

We then ran a series of linear mixed effects models using the glmmTMB function in the generalised mixed model TMB package (Brooks et al., 2017). Because our main interest is in differences between looking to the shape and material test objects, and because children's looks up to the experimenter and exemplar were driven by the explicit cue to look up at the exemplar (e.g. "*child's name, this is my kiv. . . ,*"), we calculated a proportion looking to the shape-matching test object out of the total looking to just the two test objects, dropping looks "up" or "off". We used cbind (SamplesInAOI, (SamplesTotal -SamplesInAOI)) to analyse the fixations of the target within 0.01s normalised timebins for each trial. We then ran separate beta-binomial model for before and after the naming event predicting children's proportion of looking by productive noun vocabulary (continuous) and gender and orthogonal terms as fixed effects. We included linear, quadratic, and cubic orthogonal time terms based on the shape of the curve. Subject and the orthogonal time terms were included as random effects. The shape-matching test object was coded as being the target and the material-matching test object as the distractor.

The model for before the naming event revealed no main effects or significant interactions between the variables. This suggests that before the naming event all children were looking equally to the objects. The model of visual exploration after the naming event revealed a main effect of vocabulary $z = 2.45$, $p = .01$, a significant linear time term and an interaction between the linear time term and vocabulary $z = 2.02$, $p = .04$. These results models support our other results in suggesting that after the naming event children who had more nouns in their productive vocabularies looked more to the shape matching test object than children who produce fewer nouns and did so more quickly.

2.3.3 Looking Transitions

To examine whether the naming event cued a deliberative comparison process we examined looking transitions. We ran a series of linear models with a gamma link function predicting the number of transitions after the naming event by productive noun vocabulary, where children were looking when the name occurred (at the exemplar or off), and final selection. Model comparison resulted in a final model predicting transitions by productive vocabulary (continuous) only, $z = -3.10$, $p = .002$, with random intercepts for participants. As can be seen in Figure 2.5A, the number of transitions decreased as vocabulary increased. This suggests the naming event stimulated more comparison of the objects in children with smaller vocabularies (Table 2.12).

We also examined "reaction time" which is how long it took children to

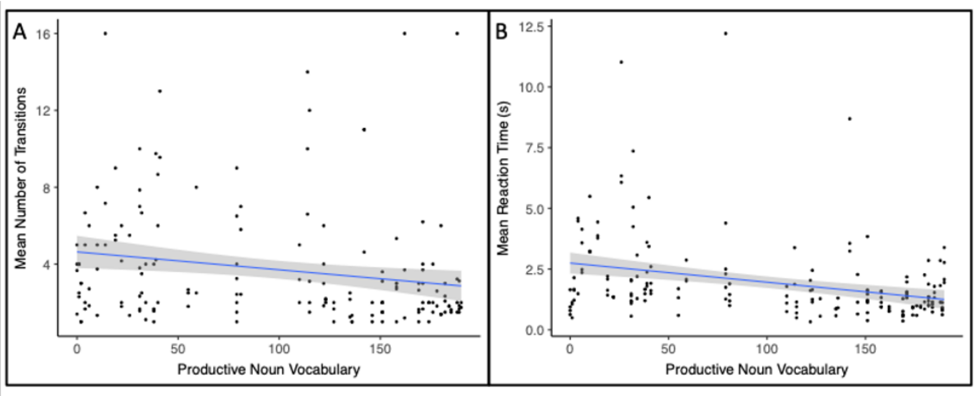

Figure 2.5: (A) Relation between the number of looking transitions after the naming event and productive noun vocabulary. (B) Relation between reaction time to look at the shape or material test object and vocabulary on the 76% of trials (614 of 808) with a first look to the exemplar following the naming event.

switch looking from the exemplar to the shape-or material-match test object on trials that started with looking to the exemplar (83% of trials). Model comparison eliminated final selection and test object as predictors, resulting in a final model predicting reaction time by productive noun vocabulary (continuous) only, t (52.03) = -3.23, p = .002, with random intercepts for participants (Table 2.13). As can be seen in Figure 2.5B, reaction time decreased as vocabulary increased. Thus, children who produced more nouns looked to the selected object more quickly and did less comparison of the test objects, while those who produce fewer nouns compared the stimuli more.

2.3.4 Attention During Familiarisation

Finally, we examined whether children had a more general bias to attend to the shape-matching test object by examining the proportion of time during the familiarisation period spent exploring the exemplar and test objects before the trial began. The mean length of familiarisation was between 12.16 – 75.35s, (M = 29.21s) and was not correlated with vocabulary (p= .57) or age (p= .26). Initial linear mixed-effects models included final selection and vocabulary (continuous), but model comparison suggested a model with a significant effect of object, $\chi^2 = 39.93$, p <.001,and random intercepts for participants was best (Table 2.14). Children explored the two test objects equally and more than the exemplar (Figure 2.6). Thus, there is no evidence of a bias to attend to the shape-match test object prior to the naming event.

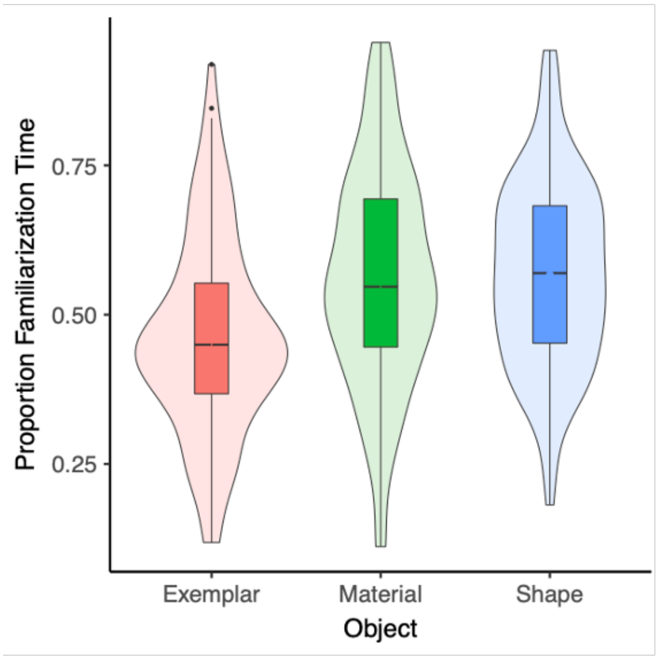

Figure 2.6: Proportion of familiarisation time spent exploring each object. Note that because children often touched or handled more than one object at once these proportions do not sum to 1.

To further examine how children's exploration of the objects during the familiarisation period related to their noun generalisation we ran a general linear mixed-effects model predicting the proportion of shape choices by vocabulary and proportion of familiarisation time spent touching each object. The final model revealed no significant predictors suggesting that exploration of the objects during the familiarisation period was not related to children's choices in the noun generalisation task (Table 2.15). Overall, this suggests that the shape bias in children's noun generalisations was not related to their exploration of the objects during the familiarisation period.

2.3.5 Analysis of Outlier Data

2.3.5.1 Overall Shape Responding

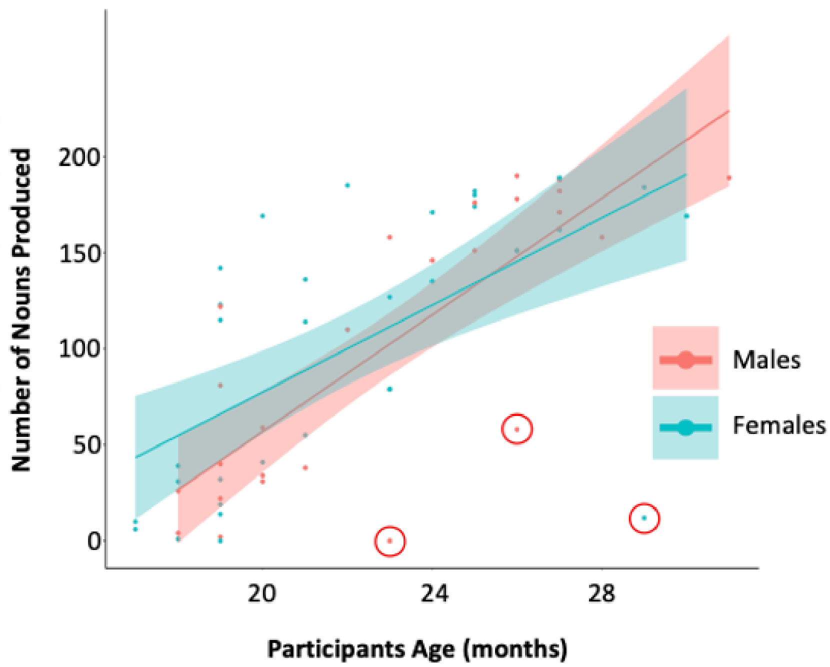

Figure 2.7: The relation between productive noun vocabulary and age for the males (red) and females (blue) in our sample. Shaded regions indicate 1.5 standard deviations of the mean for each gender. The three outlying participants are circled in red.

The productive noun vocabularies of three participants were more than 1.5 standard deviations from the mean for their age and gender (Figure 2.7). Prior research has shown that children with slower vocabulary development show differences in their noun generalisation biases (Colunga & Sims, 2017; Perry & Kucker, 2019), including finding that children with lower vocabulary for their age, who might be late talkers, don't show a shape bias (Jones, 2003). However, the three outlier children in our sample generalised novel names by shape similarity most of the time (see Table 2.1). The proportion of shape choices demonstrated by these children are likely well above chance level responding but the low number of data points limits analysis. Because of these children's strong tendency to generalise novel names to according to similarity to shape, including them with the main sample causes the significant relation between noun vocabulary and proportion shape responses to become marginal, (t (54) = 1.88, p = .066).

Table 2.1: Gender, age, total vocabulary, noun vocabulary and proportion shape responses for the three children in our sample who had total productive noun vocabularies below the 25th percentile for their age and gender

Number	Gender	Age (mo)	Age (days)	Total Vocabulary	Noun Vocabulary	Proportion shape responses
1	B	23	719	3	0	0.94
2	B	26	806	102	60	1.00
3	G	29	919	33	17	0.63

2.3.5.2 Looking Time Course

The looking trajectories of the 3 children who had very few nouns in their productive vocabularies are pictured in Figure 2.8. Note that due to the small number of data points, we could not include final decision as a factor in this visualisation. As can be seen, the gaze trajectories of these children were somewhat different to those of the main sample. In particular, these children appeared to look equally to the exemplar- and shape-matching test object before the naming event (rather than equally to the two test objects). After the naming event, these children looked more to the shape-matching test object, although some attention to the material-matching test object could also be seen. Thus, while the children in the main sample looked equally to the shape and material test objects prior to the naming event, these children with low noun vocabularies for their age showed some bias to look at the shape-

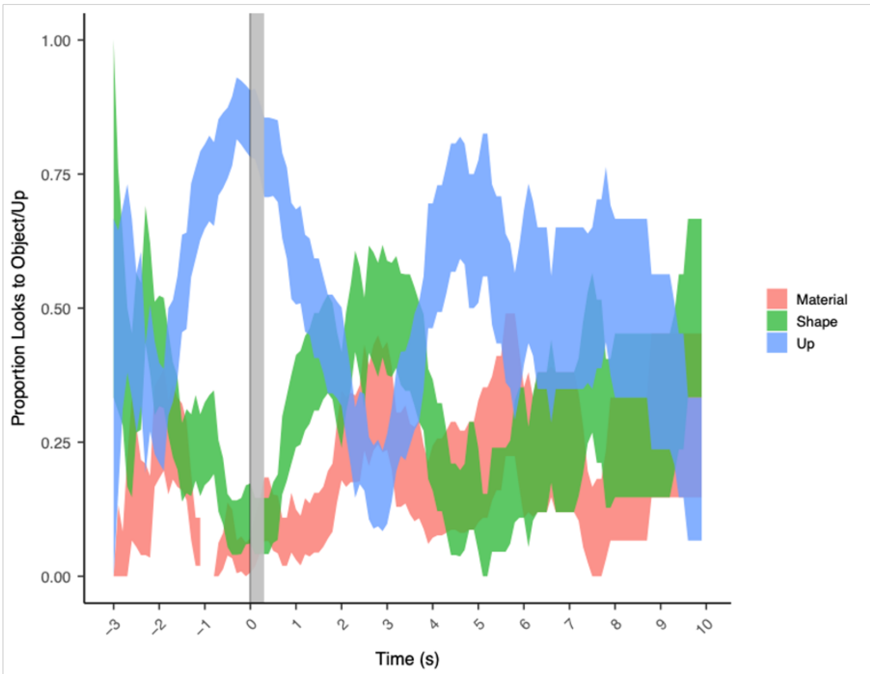

Figure 2.8: Time course of looking proportions to the exemplar and two test objects for the three outlier participants. The black dashed line represents the moment where the naming event started, and the grey bar where the analysis window begin following the naming event.

matching test object before the name was provided (see Table 2.2).

Table 2.2: Mean looking durations to the shape- and material-matching test objects before and after the naming event for the children who were outliers with respect to productive noun vocabulary

Vocabulary group	Trial Section	Look to shape (s)	Look to material (s)	Difference (s)
Outliers	Before	18.45	7.79	10.66
	After	55.60	37.81	17.79

Adding data from the outliers to the analysis of the time course of looking before the naming event still resulted in no significant main effects or interactions. Likewise, adding the outlier data to the analysis of looking after the naming event also did not change the pattern of results—final models on trials ending in a shape selection revealed a significant intercept, (z = 11.02, p <.001), and effect of vocabulary, (z = 2.32, p = .02) for trials ending in shape selections, but only a significant intercept, (z = -7.02, p= .001), for trials ending in material selections.

2.3.5.3 Looking Transitions

The outlying children appeared to have transitioned between the objects more than children in the main sample before making their generalisation selections (Figure 2.9A). When these children's data were included in the analysis of looking transitions the same pattern of results was found; children who had fewer nouns in their productive vocabularies transitioned more between the objects (Figure 2.9B). This was confirmed with a series of linear models with a gamma link function, resulting in a final model predicting transitions by productive vocabulary (continuous) only, (z = -3.512, p <.001). Thus, it again appeared that naming was more likely to cue a deliberative comparison process in children who know fewer words.

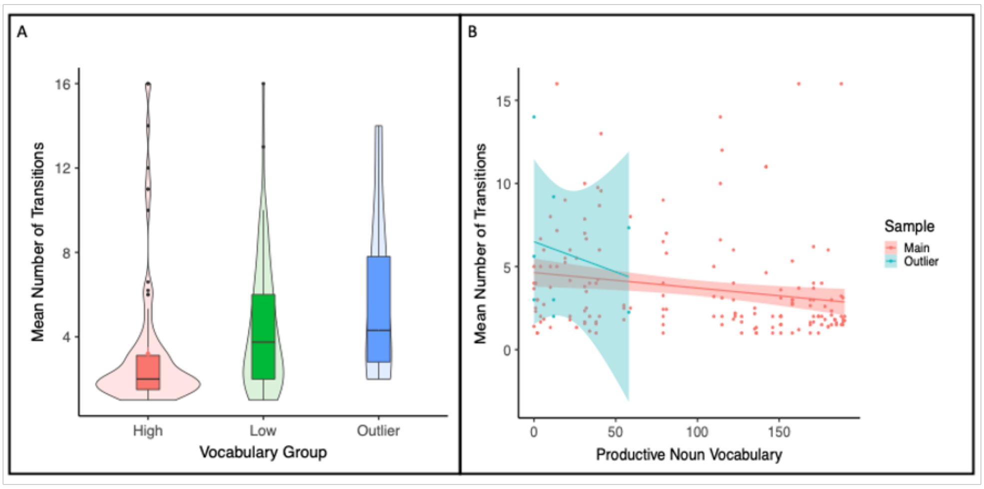

Figure 2.9: (A) Mean number of looking transitions after the naming event, for children in the high and low vocabulary groups and the three outlier children. (B) Relation between the number of nouns in the productive noun vocabulary and the mean number of looking transitions after the naming event for the main sample and the three outlier children.

The three outlier children were like those from the low vocabulary group in the time it took them to select a generalisation target (Figure 2.10A). However, the relation between their “reaction time” and vocabulary appeared to be opposite that of the main sample (Figure 2.10B). The small number of datapoints makes firm conclusions difficult. Nevertheless, when these children’s data were added to the main sample, the finding of significantly faster selections for children with more names in their productive noun vocabularies was upheld. Comparison of linear models confirmed a model predicting reaction time by productive noun vocabulary (continuous) only was best and that vocabulary was a significant predictor, (t (55.08) = -3.027, p <.001).

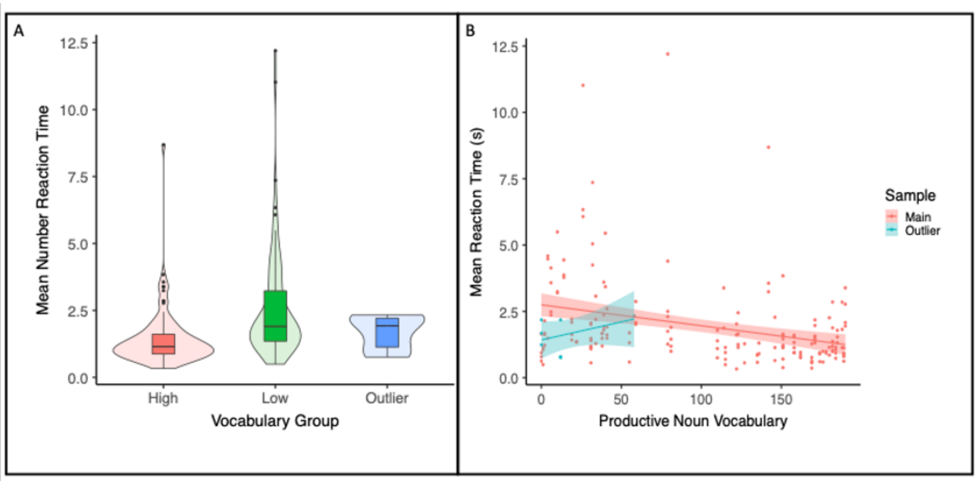

Figure 2.10: (A) Mean reaction time to select a generalisation target for children in the high and low vocabulary groups and the three outlier children. (B) Relation between reaction time and nouns in the productive vocabulary for the main sample and the three outlier children.

2.3.5.4 Attention During Familiarisation

As can be seen in Figure 2.11, during the familiarisation period the children with very few names in their productive vocabularies did not demonstrate a bias to explore the shape-matching test object more than the material-matching test object. Two of these children (outliers 2 and 3, see Table 2.3), like the main sample, did examine the two test objects more than the exemplar. The combination of a lack of preference for the shape-matching test object during familiarisation, but a bias to look at the shape-matching test as much as the exemplar once the generalisation trial proper began before the naming event (see Figure 2.8), suggests the possibility that for these three outlying children, it is something more general about the novel noun generalisation task, rather than the naming event itself, that is directing their attention to the shape-matching test object. As in the main analysis of familiarisation, a linear mixed effect model including the outliers that predicted the proportion of time spent touching each object out of total familiarisation time by object with participant as a random effect, revealed a main effect of object, $\chi^2(2) = 38.00$, $p <.001$.

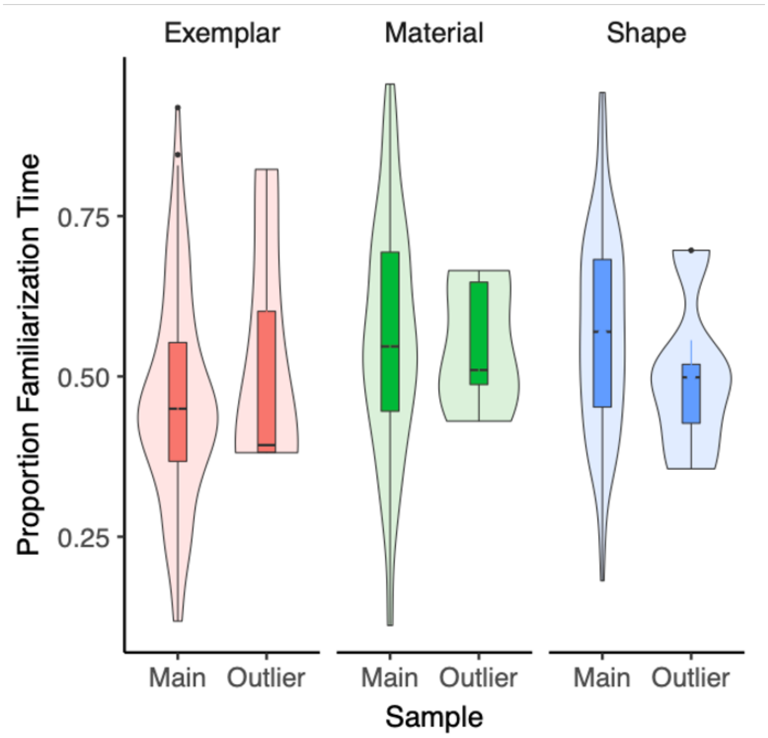

Figure 2.11: (A) Mean proportion of the familiarisation period children from the main and outlier samples spent exploring the exemplar and two test objects. Note that because children could be coded as touching two objects at a time, the proportions do not sum to 1.

Table 2.3: Proportion of time spent exploring each object during familiarisation for the three children with outlying vocabulary scores

Outlier Number	Proportion Shape	Proportion Material	Proportion Exemplar
1	0.22	0.26	0.24
2	0.33	0.32	0.25
3	0.41	0.37	0.28

2.3.6 Summary and Relation to Main Analyses

The analysis of children who were outliers in terms of productive noun vocabulary has revealed a slightly different pattern of visual exploration in the novel noun generalisation task. In the analysis without the outliers, children explored the test objects equally during familiarisation, looked at the shape- and material-test objects equally before the naming event, and looking to the generalisation target was related to the number of nouns in the productive vocabulary. The three children who had very few nouns in their vocabulary given their age appeared to be similar to children with fewer names in their productive vocabularies in the amount of time they take to make a generalisation decision and appeared to make more looking transitions between the objects before doing so. Two of these children examined the test objects and exemplar equally before the naming sequence but one focused more on the exemplar and shape-matching test object. However, unlike children in the Low vocabulary group, the vocabulary outliers looked at the shape-matching test object and the exemplar, rather than the material-matching test object, equally before the naming event. They also showed the highest proportion of shape choices, (M = .86) compared to 0.72 and 0.60 for the High and Low vocabulary groups respectively.

2.4 Discussion

The goal of this study was to explore the previously established link between noun vocabulary and children's attention to the shape of objects when generalising novel names. An issue is whether the novel name presented in novel noun generalisation tasks directly cues children's attention to shape, as suggested by the ALA (Smith, 2001), or whether a more conceptually mediated comparison process occurs between the naming event and children's final selections in the NNG task. To do this, we combined the novel noun generalisation task with a looking-while-listening procedure Fernald et al. (2008) to examine children's visual exploration and attention when learning new nouns.

We replicated prior findings that attention to shape increased with the number of nouns in children's productive vocabularies but added to this work by showing that while children looked at shape- and material-matching test objects equally before a name was presented, those who produced more nouns quickly looked to the shape-matching test object after the naming event. Interestingly, these children also looked to the material-match test object more quickly after the naming event on the smaller number of trials ending in generalisation by material similarity. These data support the hypothesis that the novel name cues attention to shape rather than cueing a deliberative comparison process, at least for children who produce many nouns. Further, the fact that children did not attend more to the shape-matching test object during the object familiarisation period before the naming sequence suggests that their attentional bias was not based on a more general preference for shape-matching stimuli.

That increased attention to shape and fewer looking transitions following the naming event were both related to the number of nouns in children's productive vocabularies further supports the proposal that the attentional cueing of novel names is learned during vocabulary development. These findings could suggest that it is the naming event activates children's previous noun vocabulary knowledge and drives attention to the most commonly relevant perceptual feature in the known vocabulary. Smith et al. (2002) proposed that because many of the first words that young English-learners acquire are names for categories of solid objects with members that share similar shapes (e.g., "spoon," "chair") their attention comes to be automatically directed to shape in the context of a naming event with a solid object. However, the data presented here also point to a developmental progression in the influence of novel words in directing attention. Although children who knew fewer nouns often generalised novel nouns by shape similarity, they took longer to make selections, were slower to look to the shape-matching test object and transitioned more between the objects following the naming event; all suggesting that for these children the name may cue a more deliberative process of comparing stimuli to guide generalisation decisions. This could possibly be because they do not yet have enough names for solid objects or categories organised by shape in their vocabularies for the novel word in the naming event to immediately direct their attention.

The data from the three children who knew few words for their age and gender largely fit with the findings from the main sample. Overall, these three children performed similarly to the low vocabulary group of the main sample, taking a similar amount of time to make their generalisation decision and doing more looking transitions than children who know more words. However, the three outlying children did look more to the exemplar during familiarisation, and less to the material-matching test object, and they showed the highest rate of shape responding overall. The low number of vocabulary outliers makes it hard to draw firm conclusions. However, they do support the inference in the analysis with the main dataset that some shape-biased noun generalisations for children with fewer names in their vocabularies may not be driven by an automatic link between the naming event and attention to shape. Instead, for some children, attention to shape in the novel noun generalisation task may result from a more deliberative comparison process.

While the children in this sample were very young to be diagnosed with SLI/DLD, the slower responding of children with lower vocabulary might be related the prior findings by Collisson, Grela, and Spaulding (2015) and Vlach and DeBrock (2017). Collisson et al. (2015) and Vlach and DeBrock (2017) overall found that children with lower vocabulary perform worse in tasks involving pairs of novel symbols compared to children with higher vocabulary. Children with better memory for object pairs are more likely to exhibit word learning biases beneficial for vocabulary growth. In particular our data indicating the three outlying children showed a different pattern of visual exploration. This could reflect a need to look back and forth between the exemplar, shape and material match because they did not have a representation of the object formed in their memory due to a less well developed working memory system.

One interesting possibility is that this difference might be related to differences in memory processes. Working memory has been shown to be weaker in children with language delay (Blom & Boerma, 2019; Smolak, McGregor, Arbisi-Kelm, & Eden, 2020; Vissers, Koolen, Hermans, Scheper, & Knoors, 2015), and Collisson et al. (2015) demonstrated that children with SLI, who did not show a shape bias, performed more poorly on a test of visual object memory. Thus, it is also possible the differing pattern of visual exploration seen in the vocabulary outliers is related to less robust memory processes, a conclusion that fits with a recent meta-analysis of visual working memory and vocabulary development (Pickering et al., 2023). Not being able to maintain robust memories of the exemplar and both test objects could result in children needing resample the stimuli more by looking back and forth between them. In this way then, children with smaller vocabularies might be seen to deliberatively compare the objects before making a decision.

The nature of this deliberative process will be an important target of future work to understand how words guide attention and children's few-shot generalisation abilities. Are children comparing stimuli to determine the kind of thing they are? Or is the greater number of looking transitions shown by children with smaller noun vocabularies indicative of a need to refresh the working memory representation that supports directed visual exploration? This latter possibility fits with Vales and Smith's (2015) proposal that the influence of names on preschoolers' visual search (Vales & Smith, 2015), visual sampling (Carvalho et al., 2018), and object identification (Vales & Smith, 2018), stems from improved working memory representations of visual stimuli created when names are provided. However, while the contribution of working memory to vocabulary development is well established, the more specific contribution of visual working memory is less clear (see Pickering et al., 2023).

In line with prior literature, our data support the argument that the shape bias is acquired during vocabulary learning (Smith et al., 2002), particularly studies that show the shape bias is linked to the number of nouns children know (Samuelson & Smith, 1999; Gershkoff-Stowe & Smith, 2004). Like those studies we found a relation between the number of words in children's productive noun vocabularies and their tendency to generalise novel nouns by similarity in shape. Further, the current study is one of the first to demonstrate a link between the shape bias and vocabulary using a British-English measure of vocabulary, the first being Horst (2013) who also showed that the British-English measure of vocabulary they used a UK adaptation of the MacArthur–Bates Communicative Development Inventory: Words and Sentences (Klee & Harrison, 2001) which had similar American-English measures in the composition names for solid/nonsolid things and categories organised by similarity in shape, material and colour.

Interestingly, however, unlike some prior studies of the relation between vocabulary and the shape bias, we did not use count noun syntax in our task. While Smith has proposed that it is the count noun syntax that cues children's attention to shape, other work has suggested that including solid objects in the task may be enough. In particular, Samuelson's (2002) simulation work showed that connectionist networks trained with statistics that match those learned in early vocabulary development can learn a shape bias, even when count noun syntax is not included in the task. The fact that count noun syntax is not needed to produce the bias, could suggest that the bias has its roots in a visual attention system that prioritises attention to shape. That is, children may learn the kind of vocabulary that creates a shape bias because their visual systems are, from the start, better able to encode information about categories organised by shape. This then creates a biased vocabulary that comes to further support more learning of categories organised by shape similarity.

In this context, it could be that the children in our sample with smaller vocabularies have fewer nouns in their vocabulary because they had difficulty in noun acquisition. This suggestion is in line with recent data examining the vocabulary structure of "late talker" toddlers, those below the 15th vocabulary percentile for their age and gender. (Perry, Custode, et al., 2022) found that late talkers who have a smaller proportion of nouns naming categories of objects organised by shape similarity in their vocabulary are more likely to continue to be slow to learn nouns. Additionally, children who are diagnosed with Developmental Language Disorder are more likely to have had a smaller proportion of names for categories organised by similarity in shape in their vocabulary as toddlers.

The relation between vocabulary and attention is likely not unidirectional. Rather, both may be part of a cascade of processes that are co-evolving and mutually reinforcing. It is a fact that concrete objects are easier to pick up and manipulated which means that children may have increased experience with them (Perry & Lupyan, 2014). This experience could help to train the young visual and attentional systems. Similarly, parents and children talk about solid things more so their labels are more frequent in the input (e.g., Perry, Kucker, et al., 2022). This then influences what words enter the vocabulary first and biases what things are easier to learn next (e.g., Hills, Maouene, Riordan, & Smith, 2010). Each step in this cascade has the possibility of interactions between word learning mechanisms and perceptual mechanisms such that one feeds the other creating a snowballing process that supports future learning. In such a cascade, however, there is also the chance for differences between children to emerge with some differences leading to less future learning and potential developmental delay. This cascade would also likely involve the action and development of multiple additional cognitive processes such as memory, response inhibition, and speed of processing (see, e.g., Samuelson, 2021). Indeed, this possibility is part of the motivation for the subsequent studies presented in this thesis.

2.4.1 Limitations and Future Directions

It would be useful for future work to examine the relations of the novel noun generalisation with other processes in more depth. Specifically, currently each participant had only one session in the study. Thus, we do not know how stable participant's performance was. The use of multiple sessions for each child in the future studies could provide richer data about the relation between children's choice and looking, as well as how their vocabulary classifications influenced their generalisation decisions

Another potential issue with the sample is that all our children attended to mostly to shape when generalising the novel names. It would be useful to recruit even younger children, or children who do not pay as much attention to shape, to obtain a more complete picture of how vocabulary and shape relate. Also, we have not considered their previous experiences such as SES and how it might influence their performance on this task, as most of our participants came from high- and middle-income households and had highly educated parents. In the future, it would be interesting to see whether this played a role in their performance by collecting a sample from more inclusive background.

Future work could also look at the role of memory processes and the possibility that differences in children's attention to shape when generalising novel nouns, and their vocabulary development, is related to memory differences. Research has suggested that remembering novel pairings of visual stimuli may be one difficulty facing children with slow vocabulary development, in this case children with SLI (Collisson et al., 2015). Similarly, Vlach and DeBrock (2017) also demonstrated a link between visual paired associate (VPA) learning and vocabulary, suggesting that multiple cognitive domains, particularly memory, significantly contribute to the development of word learning skills. This extends beyond age and vocabulary, suggesting that memory capabilities are vital to early word learning development and fits with a recent meta-analysis that showed links between visual working memory and vocabulary development (Pickering et al., 2023).

2.5 Conclusion

This examination of children's attention and choice in the NNG task, together with their vocabulary level, has shed new light on the developmental cascade of word learning. It shows the tight connection between the naming event and attention to shape in the NNG task with solid objects and that this is dependent on the number of nouns in the productive vocabulary. But it also reveals that for some children with fewer nouns in their vocabulary, shape choices may be the product of more deliberative comparison processes. The final study in this thesis seeks to understand this possibility more by examining both attention during novel noun generalisation and memory abilities in individual children. In particular, we are interested in working memory and also specifically children's memory for objects, Thus, a task that can effectively measure memory for objects in children from the age range studied here was required. The next chapter describes findings from a task we developed to measure object memory in children from 14-to 26-months of age.

2.6 Significance Tables

Table 2.4: Regression results for proportion shape choice by gender, noun vocabulary and set

Variable	Estimate	Std.Error	t	p-value
(Intercept)	0.17	0.04	4.27	$< .001^{***}$
Gender_sc	-0.10	0.08	-1.26	.21
OCDI_2_10_sc	0.03	0.04	0.77	.44
SetKiv	0.02	0.06	0.42	.67
SetMip	-0.03	0.06	-0.50	.62
SetZup	-0.02	0.06	-0.30	.77
Gender_sc:OCDI_2_10_sc	-0.11	0.08	-1.43	.15
Gender_sc:SetKiv	0.05	0.11	0.44	.66
Gender_sc:SetMip	0.08	0.11	0.73	.47
Gender_sc:SetZup	0.10	0.11	0.87	.38
OCDI_2_10_sc:SetKiv	0.08	0.06	1.50	.13
OCDI_2_10_sc:SetMip	0.04	0.06	0.70	.49
OCDI_2_10_sc:SetZup	-0.00	0.06	-0.06	.95
Gender_sc:OCDI_2_10_sc:SetKiv	0.08	0.11	0.73	.47
Gender_sc:OCDI_2_10_sc:SetMip	0.04	0.11	0.33	.74
Gender_sc:OCDI_2_10_sc:SetZup	0.02	0.11	0.15	.88

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.5: Regression results for proportion shape choice by gender and noun vocabulary

Variable	Estimate	Std.Error	t	p-value
(Intercept)	0.17	0.02	7.41	$< .001^{***}$
Gender_sc	-0.04	0.05	-0.95	.35
OCDI_2_10_sc	0.06	0.02	2.65	$.01^{**}$
Gender_sc:OCDI_2_10_sc	-0.08	0.05	-1.83	.07

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.6: Regression results for looking time course before the naming event by final selection and noun productive vocabulary

Variable	Estimate	Std.Error	z	p-value
(Intercept)	0.08	0.09	0.87	.39
Final_Selection_s	-0.25	0.17	-1.41	.16
OCDI_2_10_sc	0.04	0.09	0.42	.67
Final_Selection_s:OCDI_2_10_sc	-0.01	0.17	-0.08	.93

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.7: Regression results for looking time course after the naming event by final selection and noun productive vocabulary

Variable	Estimate	Std.Error	z	p-value
(Intercept)	-0.02	0.09	-0.26	.80
Final_Selection_s	2.33	0.19	12.02	< .001***
OCDI_2_10_sc	-0.04	0.09	-0.48	.63
Final_Selection_s:OCDI_2_10_sc	0.46	0.19	2.47	.01**

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.8: Regression results for looking time course by noun productive vocabulary after the naming event for shape final choice

Variable	Estimate	Std.Error	z	p-value
(Intercept)	1.29	0.12	10.60	< .001***
OCDI_2_10_sc	0.23	0.11	2.04	.04*

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.9: Regression results for looking time course by noun productive vocabulary after the naming event for material final choice

Variable	Estimate	Std.Error	z	p-value
(Intercept)	-1.20	0.18	-6.80	< .001***
OCDI_2_10_sc	-0.21	0.17	-1.26	.21

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.10: Regression results predicting children's final selection by proportion looking to the shape-match test object before the naming event

Variable	Estimate	Std.Error	z	p-value
(Intercept)	0.80	0.16	5.01	< .001***
Prop	-0.02	0.20	-0.10	0.92
OCDI_2_10_sc	0.11	0.16	0.72	.47
Prop:OCDI_2_10_sc	0.33	0.20	1.63	.10

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.11: Regression results predicting children's final selection by proportion looking to the shape-match test object after the naming event

Variable	Estimate	Std.Error	z	p-value
(Intercept)	-1.94	0.21	-9.32	$< .001^{***}$
Prop	4.96	0.34	14.50	$< .001^{***}$
OCDI_2_10_sc	-0.08	0.21	-0.38	.70
Prop:OCDI_2_10_sc	0.45	0.33	1.37	.17

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.12: Regression results for transitions of looking to the test objects by productive noun vocabulary

Variable	Estimate	Std.Error	z	p-value
(Intercept)	1.22	0.07	17.42	$< .001^{***}$
OCDI_2_10_sc	-0.22	0.07	-3.10	$.002^{**}$

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.13: Regression results for reaction time by productive noun vocabulary

Variable	Estimate	Std.Error	df	t	p-value
(Intercept)	1.98	0.19	52.53	10.60	$< .001^{***}$
OCDI_2_10_sc	-0.61	0.19	52.03	-3.23	$< .001^{***}$

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.14: Chi-Square Test results for children's familiarisation data

Variable	Chisq	Df	p-value
(Intercept)	633.03	1	$< .001^{***}$
object	39.93	2	$< .001^{***}$

Note. **p*<.05. ***p*<.01. ****p*<.001.

Table 2.15: z statistics for model predicting proportion of shape choices by vocabulary and proportion familiarisation time spent touching the exemplar, shape-matching or material-matching test object

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	0.55	0.42	1.31	.19
Vocabulary	0.00	0.00	0.46	.65
PropFamShape	-0.11	0.50	-0.22	.82
PropFamMaterial	-0.23	0.46	-0.50	.62
PropFamExemplar	-0.12	0.47	-0.26	.80
Vocabulary: PropFamShape	0.00	0.00	0.49	.62
Vocabulary: PropFamMaterial	0.00	0.00	0.27	.79
Vocabulary: PropFamExemplar	0.00	0.00	0.43	.67

Note. *p<.05. **p<.01. ***p<.001.

Chapter 3

The relation between children's object memory and vocabulary

3.1 Introduction

Individual cognitive development and vocabulary growth are intricately interconnected. Specifically, cognitive development, which involves the advancement of thinking, problem-solving and memory capabilities, is a critical underpinning of vocabulary acquisition (Cowan, 2014). As children's cognitive abilities mature, particularly attention and categorisation skills, they become more adept at learning and retaining new words (Rose et al., 2009). Additionally, developments in memory allow children to retain and process more complex and abstract information, including new vocabulary (Wojcik, 2013).

A robust vocabulary fuels cognitive growth, and research indicates that word learning supports cognitive skills and facilitates vocabulary acquisition. However, each child is also unique in their developmental trajectory; it is evident that there are noticeable differences in vocabulary acquisition, phonological abilities, social and pragmatic skills, as well as in their demographic contexts (Perry & Samuelson, 2011). Given the interconnectedness between vocabulary development and broader cognitive processes, one would expect that individual children's characteristics and variations in language skills would be intertwined with distinct cognitive capabilities and influenced by personal backgrounds.

Given this complex interplay between cognitive development and vocabulary growth, it is not surprising that there is wide variability in children's vocabulary development. Initially, children from one year of age typically add one or two new words to their productive vocabulary weekly. However, they experience a much more rapid vocabulary expansion in the second half of their second year. This surge, often referred to as a "vocabulary spurt", is influenced by several factors. These include the child's cognitive development, the socioeconomic environment and background of the family, and the extent of language exposure children receive (Samuelson & McMurray, 2017).

These differences are seen in the range of vocabulary size of children of a given age. For example, at 16 months of age, parents report that children in the upper 10% for vocabulary development know 157 words, while those in the lowest 10% may only know four words. Similarly, by approximately 30 months, children in the upper 10% for vocabulary development are reported by parents to know 664 words, while those in the lowest 10% may only know 234 words (Frank, Braginsky, Yurovsky, & Marchman, 2017). These individual differences in the number of words known at any age are also seen in children's vocabulary growth trajectories. For instance, most 24-month-olds who are learning vocabulary at a typical rate will continue to do so, eventually producing thousands of words and entering school with a robust, productive vocabulary. However, some children deviate from this typical rate and may experience late-emerging language difficulties. Among these, children with smaller vocabularies who fall at or below the 15th percentile for their age and gender are often categorised as "late talkers" (MacRoy-Higgins & Montemarano, 2016; Rescorla, 2011; Perry & Saffran, 2017; Perry, Kucker, et al., 2022). A significant number of children initially identified as "late talkers" will eventually catch up and attain an average level of vocabulary by the time they enter school. However, some will continue to exhibit weaker language skills. These children, often referred to as "late talkers", progressively reach vocabulary levels within the normal range as they advance through their school years (Rescorla, 2011; Singleton, 2018). However, many will continue to have some difficulties with language well into adolescence (McGregor et al., 2022). The current work explores the differences in underlying processes that contribute to the varied successes in vocabulary acquisition among children.

Understanding both how children learn words as well as they do and why some struggle is critical, as early vocabulary development is predictive of later outcomes such as school success. Research by Morgan, Farkas, Hillemeier, Hammer, and Maczuga (2015) found that at the group level, 24-month-old children with larger oral vocabularies exhibited greater reading and mathematics achievement and increased behavioural regulation at kindergarten entry. Additionally, a study by Marchman and Fernald (2008) demonstrated a significant link between vocabulary at 25 months and later language and cognition, underlining the importance of early vocabulary for school-age years. This suggests that a toddler's status as a late talker could potentially predict future language difficulties. In line with this, researchers have suggested that expressive language screening between 18 and 35 months could identify children with receptive language delays, who may also experience other intellectual disabilities or hearing impairments or face demographic risks (Rescorla, 2011; Singleton, 2018). However, even with the knowledge of late-talking children who are at risk of later language delay, there is the additional question of how best to support them to a better vocabulary development trajectory. The challenge lies in the fact that learning even a single new word depends on a number of cognitive processes.

3.1.1 How children learn words

For children to learn words, they must form associations between words and objects. Some of these associations are learned through object manipulation and caregiver labelling in their naturalistic settings (West & Iverson, 2017). Interactions with objects are crucial in developing cognitive processes, such as understanding cause-and-effect relationships, developing memory and categorisation skills and enhancing perceptual abilities. But mapping a novel word to an object in the environment requires a process of referential mapping. For instance, consider a scenario where a baby is sitting in a highchair during mealtime, and the mother says, "Try the banana". If the child has never heard this word or seen this fruit before, they must undertake considerable work: identifying the words, finding the referent, mapping the word to the object and locating the object to respond. Additionally, they need to remember the object, words and their mapping to integrate the new word into their vocabulary. Thus, the task of learning even a single new word means mapping a novel word to an object, which involves multiple cognitive processes, including visual exploration, object recognition, formation of associations, and various memory processes, which also use the auditory process.

Research indicates that by the end of their second year, young children can segment continuous speech to identify individual words and then link them to referents in the world (Saffran et al., 1996; Jusczyk, 1999). Additionally, by the mid-second year, toddlers are capable of mapping word forms, segmented from spoken language to novel objects (Graf-Estes, Evans, Alibali, & Saffran, 2007; Hay et al., 2011). Visual memory plays a complementary role in this process. When infants hear a word and see a corresponding object simultaneously, they are not just relying on auditory cues but also engaging their visual memory to link the sound with the image (West & Iverson, 2017). This multimodal integration enhances their ability to remember and recognise words and objects (Rose, Feldman, & Jankowski, 2004). Findings from Gathercole and Adams (1994) also support this as they found that only non-word repetition correlated with vocabulary development. Non-word repetition tasks assess children's ability to remember novel auditory sequences and are often used to identify early potential difficulties with language and vocabulary development (Gathercole, Pickering, Knight, & Stegmann, 2004; Coady & Evans, 2008; Gathercole & Pickering, 2000). While auditory memory is crucial for processing and storing spoken language, visual memory is more important for forming and recalling the visual representations of objects associated with those words. Visual object memory is the ability to remember objects to support later recognition of visual stimuli and is crucial for learning the names of concrete objects (Rose et al., 2004). Given that the referent is likely a concrete thing in the scene and that learning the name will require remembering features of this object, learning the names of tangible objects hinges on visual processes like object recognition and the memory of previously named objects. For instance, if the child had previously seen a yellow banana, when mum names and they make a link between the word and the object, it is likely the previous representation of the banana will help make the new mapping strong and easier to retrieve later (c.f, Kucker & Samuelson, 2012). But there is still another task the child must have learned, the new mappings—generalise the name to a new instance of the item. Here memory for specific features of the object will likely help the child connect previous and current instances and make the connection between the name and multiple instances of the category (c.f., Vlach, 2016).

Recent research has established a link between children's abilities to represent and remember objects and vocabulary development. We aimed to explore differences in children's abilities to remember pairs of visual objects and the relation of this ability to vocabulary development. Before describing the current study, we reviewed recent studies investigating toddlers' evolving abilities to represent and remember objects, their capacity for remembering associations, and the connection of these skills with early vocabulary development. We particularly focused on how these abilities vary among children. We finished with a review of two recent studies that establish links between toddlers' memory for pairs of visual objects and their language and vocabulary development, providing direct motivation for the current experiment.

3.1.2 Remembering objects, Forming Associations and Vocabulary Development

To learn words for concrete objects, children need to form robust associations between names and objects. Several recent studies demonstrate developmental changes in toddlers' ability to represent and remember objects, form associations between names and objects, or between pairs of objects, and how these abilities are related to vocabulary development. In their 2023 systematic review and meta-analysis, Pickering et al. (2023) uncovered a notable link between the ability to remember pairs of visual stimuli and vocabulary development. They found a positive correlation suggesting that individuals with stronger visual memory skills, particularly in tasks requiring the recall and recognition of visual pairs, tend to have a richer vocabulary. They emphasise the importance of visual memory in early language acquisition stages. This is further confirmed in several recent studies examining relations between aspects of memory and early vocabulary development. These studies examine both aspects of what children remember, such as specific features, and developments in memory processes, such as how aspects of presentation and familiarity of objects may influence early memory (Obeid & Brooks, 2018). Further, these studies show ties to vocabulary, either in relations to vocabulary size and memory abilities or a role for words in supporting memory (Vukovic & Lesaux, 2013).

Working memory (WM), as described by Baddeley (2012) and Baddeley and Hitch (1994), plays a pivotal role in tasks requiring short-term storage, such as remembering objects. Specifically, visual working memory, (VWM) is a type of working memory which emerges in infancy and early childhood. VWM is used to understand how children remember new word-object mappings and are reshaping perspectives on their learning processes overall. According to Vales and Smith (2015), it has implications for children's vocabulary development and informs the understanding of how children process information. In their research, Vales and Smith (2015) emphasise that visual search, an active scan of an array, is thought to be directed by working memory representations. These representations naturally lead to more visual attention being paid to items in the array that match the VWM's contents. Specifically, their 2015 study revealed that 3-year-olds exhibit enhanced object recognition when provided with labels for objects at presentation. This activation of stronger visual memory representations was observed through a visual search task, where children were presented with a target object either silently, with its label, or with a different phrase. Children showed the fastest recognition of the correct object when labels were provided, indicating that labels facilitate the recognition of object shapes in VWM. However, the precise nature of this facilitation was not immediately apparent.

To investigate further, Vales and Smith (2015), conducted another task in which children had to search for the same target object over repeated exposures, presented either with a label or in silence. Their results showed that labels mimic the effect of repeated visual exposure. Visual search times in the first trial with labels matched those after several trials in the silent condition. This suggests that having active representations in working memory supports visual attention; acting as a shortcut and using stronger memory representations. This underscores a tight connection between words and visual representations.

Children's memory for visual objects is also influenced by the properties of object categories, and the names for these categories. Although an individual object might have multiple dimensions that define its category, such as colour, texture and size, recent research suggests that object shape, in particular, is fundamental to many of the nominal categories that children learn first. There is a strong body of literature indicating that young language learners are particularly biased towards object shape when learning new words.

Perry and Saffran (2017) investigated how toddlers' existing vocabulary impacts their ability to recognise and categorise objects based on colour and shape. They showed children images of two familiar objects, some in atypical colours (like a pink cow instead of a regular black and white one). The findings showed that toddlers with larger vocabularies demonstrated greater flexibility in their lexical representations, enabling them to correctly identify objects despite their atypical colours. These findings imply that toddlers' understanding of words is influenced by their vocabulary size and the specific attributes they associate with objects. This effect was more pronounced in toddlers who had fewer shape-based words in their vocabulary, suggesting a link between vocabulary development and how toddlers process object properties This suggests that a more extensive vocabulary allows children to generalise and categorise objects based on more abstract features. Their research highlights the importance of enriched lexical knowledge in facilitating robust and adaptable cognitive representations, thereby enhancing children's capacity to process and retain new information. This study underscores the critical role of vocabulary development in supporting cognitive flexibility and efficient information processing in early childhood.

The way children categorise objects is related to how they remember them, which is why a shape bias, as a memory bias, has been suggested to influence this ability (Vlach, 2016). This study, examined the relation between object categorisation and memory retention in young children, drawing on the shape bias, the tendency to generalise new words based on object shape rather than other attributes such as colour or texture. Vlach (2016) conducted experiments where children were shown novel objects and later tested on their ability to recall and categorise these objects based on their shape. The findings revealed that children exhibited stronger memory retention for object categories that were represented by objects that were similar in shape, indicating that categorisation by shape enhances memory encoding and retrieval processes.

This suggests that cognitive biases, like the shape bias, significantly influence how children process and retain information and highlights that biases in categorisation can directly affect memory performance.

A link between object name learning and memory for object shapes has been found to influence learning words and be related to the number of words children know (Smith, 2003). According to Jones and Smith (2005), late talkers exhibit poorer object recognition, which negatively influences their ability to connect colourless, caricature-like shapes to their life-like object counterparts. In their study, Jones and Smith (2005) assessed how well children could recognise and match simplified shapes with their real-world versions. They found that late talkers were less able to recognise caricatures of objects, which indicates that a difficulty in recognising and connecting visual shapes to real objects can affect language acquisition. This finding suggests that delayed language development can be impaired by visual recognition skills.

Further research by James, Jones, Smith, and Swain (2014) and Slone, Smith, and Yu (2019), supports the connection between visual exploration and object representation. James et al. (2014) explored the quality of visual exploration in children and its impact on forming object representations. Their study found that children who engaged in robust and varied visual exploration developed stronger and more diverse object representations. Similarly, Slone et al. (2019) demonstrated that active visual exploration in different contexts enhances object recognition. They showed that children who thoroughly explored objects were better at recognising these objects later. This enhanced object recognition, resulting from visual exploration, leads to quicker and more effective learning of object names. Both studies by Slone et al. (2019) and James et al. (2014) highlight that when children can explore objects extensively, they create stronger mental representations, which facilitates faster and more accurate vocabulary acquisition. Therefore, the ability to remember objects and their associations during the toddler years is closely related to vocabulary development, emphasising the importance of both visual exploration and cognitive development in early language learning.

Just as recent work shows that visual search is enhanced with labels, other work shows critical developments in memory for new word-object associations between two- and three-years of age. Various studies have investigated how young children learn and remember new word-object associations, which is a crucial process for their cognitive development. Different processes are involved in choosing the right object for a new word (reference selection) and remembering the new word-object mapping (lexical retention). Referent selection is the process by which children find what a word is referring to (Sia et al., 2023). Horst and Samuelson (2008) explored the processes that link referent selection and word learning through four different experiments. Specifically, 24-month-old infants were shown both familiar and novel objects and asked to pick the referents of several familiar and novel names. They were then tested for retention of the novel word-object mappings after a 5-minute delay. The use of this delay enabled the retrieval to occur from long-term memory. They found that children were good at reference selection but not good at retention. Horst and Samuelson (2008) suggested that the processes of selecting referents and retaining new word object mappings unfold over two different time scales: within a single attempt to choose the right object and over a longer timescale of multiple exposures.

Subsequently, Bion, Borovsky, and Fernald (2013) expanded this understanding by examining these processes in children of different ages: 18-, 24- and 30-month-old children. In their task children were shown one familiar and one novel object on a screen while listening to sentences that named one of the images. They evaluated how children learn and retain new word-object associations. Similar to Horst and Samuelson (2008), Bion et al. (2013) also found, that 24-month-old children were unable to retain novel word object mappings after limited presentations. However, they found that the referent of a novel word in ambiguous contexts is a skill that improves from 18 to 30 months of age, and children are able to retain new mappings at around 30 months. They concluded that the ability to find the referent of a novel word in ambiguous contexts improves gradually over time and is related to the overall vocabulary size of the children.

Kucker and Samuelson (2012) asked what was needed for 24-month-olds to form strong enough word-object representations to demonstrate retention after a delay. Their study examined the role of familiarity with the objects and words on infants' ability to bridge between the initial fast mapping of a name and object and following retention in the service of slow mapping. They followed a methodology similar to that of the previous studies. However, before the referent selection trials, the children were made familiar either with the novel word or the novel object via a short pre-familiarisation phase. Their findings revealed that infants could retain novel mappings formed after pre-familiarisation with the words after a delay. However, when familiarised with the novel words, this did not occur. These results suggest that familiarity with the object before a new word-object mapping is created, enhances children's retention of the mapping.

3.1.3 Visual object memory and children's learning of words

One way that investigators have examined children's memory for objects is via visual paired association tasks (Vlach & DeBrock, 2017). Such tasks examine children's memory for pairs of objects and thus children's abilities to form associations between pairs of objects (McGregor et al., 2022). This link between the ability to aggregate and remember word-referent pairings and vocabulary development can be seen in a recent study by (Vlach & Johnson, 2013). In a sample of 32 infants aged 16 and 20 months these researchers investigated children's ability to remember new word object mappings. They used a cross-situational word learning (CSWL) task, which involved a learning and a testing phase of novel linguistic label and object presented. They found that both 16- and 20-month-old infants could learn new mappings pairings presented in immediate succession to each other. However, only the 20-month-old infants could correctly infer pairings distributed across time (Vlach & Johnson, 2013). They suggest that the younger infants were not able to retrieve memories of previously formed mappings as well as the older infants. Thus, when a mapping was repeated after a delay in the spaced condition, they were not able to build on the prior representation, and learning was not as strong.

Two other recent studies suggest a link between children's memory for pairs of objects and their vocabulary. Collisson et al. (2015) used verbal instructions and a story about helping a detective to test children's ability to remember pairs of symbols and pictures. Specifically, three- and four -year-old children were asked to remember a novel object paired with a novel symbol. Half of the children tested had SLI and the other half were typical language learners. In the test, the children were presented with two previously seen symbols on a laptop screen and asked to select the one that had previously been seen with a target image displayed at the top centre. Each symbol appeared once as a target and once as a foil. Children were presented with multiple learning and test trials for each symbol-image pair over multiple days of testing. The study also included vocabulary data collection. A significant finding was regarding pre-schoolers' performance in the visual paired-associate learning task and their vocabulary development. Specifically, the performance of typical learners steadily improved and they had more correct responses across the days of testing, but in the SLI group, performance stayed at chance even on the last day of testing. The authors conclude that the ability to remember novel pairings of visual stimuli may be one difficulty facing children with slow vocabulary development, in this case children with SLI.

Similarly, Vlach and DeBrock (2017) demonstrated a link between visual paired associate (VPA) learning and vocabulary. They conducted two tasks: one involving CSWL and the other a paired associates memory task, both involving preschool-aged children. They also gathered data on vocabulary development. Vlach and DeBrock (2017) tested children from a wide age range: 22 to 66 months, with a mean age of 47.81 months. Children were first trained on pairs of pictures presented on a screen. At test, children were shown a target picture and two choice options. The experimenter then asked the children to indicate which choice picture went with the target. They found a relation between children's performance on the task and their vocabulary size. They also found that VPA performance was related to performance on the CSWL tasks. Thus, this study highlights the connection between visual object memory and children's learning of words associated with concrete objects. The results showed that multiple cognitive domains, particularly memory, significantly contribute to the development of CSWL in children. This extends beyond age and language abilities, suggesting that memory capabilities are vital to early language development.

3.1.4 The current study

The current study builds on the prior work by Collisson et al. (2015) and Vlach and DeBrock (2017) to examine the relation between object memory and very early vocabulary development; in particular, during the period of rapid early vocabulary growth from 14-26-months-of-age. The procedures used by Collisson et al. (2015) and Vlach and DeBrock (2017) are not suitable for testing this age range as they both used tasks that required explicit responses which children as young as 15-months of age are unlikely to produce reliably without extensive training (see Donnellan et al., 2019; McGillion et al., 2017). For this reason, our task utilised eye tracking in a preferential-looking procedure. It is structured similarly to that of Vlach and DeBrock (2017). However, rather than requiring explicit responses we measured children's memory via their preferential looking to a target object that had previously been paired with a provided cue object. Specifically, our task examined whether the presentation of a previously seen visual image primes infants' gaze during a subsequent presentation of a pair of images, including one that had previously been presented with the prime and a second that had not.

On each trial, children were presented with a memory array consisting of a pair of objects. They were then presented with a probe item that was either one of the items from the memory array—an "associated" probe—or an unrelated item, a "random" probe. This was followed by a test array consisting of an item from the memory array (not the probe) and a foil item. We measured whether children were more likely to look at the item that had been seen in the memory array, following an associated probe versus a random probe. We also varied whether the objects presented were likely to be familiar to children in the target age range, or novel, unfamiliar items.

We considered two possible hypotheses regarding children's memory for visual objects and their vocabulary development:

- The first hypothesis was that children with more words in their vocabulary would create more robust memories for pairs of objects. Children would look more to the target object following associated probes compared to random.

- Children would find it easier to remember pairs of familiar objects that they may already be able to represent. The difference in children' looking following associated and random probes would be higher on trials with familiar stimuli.

3.2 Method

3.2.1 Participants

A total of 46, 14-26-month-old children (20 females) with a mean total productive vocabulary of 153.24 words, (*SD* = 125.76 *Median* = 123.5) participated. Children were from a medium-sized city in the East of the UK and had normal or corrected-to-normal vision. Data from 10 additional participants were excluded because they did not complete at least one of each type of trial (n=7), failed to return the vocabulary questionnaire (n=2), and due to technical problems (n=1). Informed consent was obtained from the parents prior to the experiment. All children received a small prize for participation. This project received ethical approval from the ethics board of the University of East Anglia (Project ID: 2021-0596-002456).

3.2.2 Apparatus

A 24-inch BenQ Zowie XL2430 (up to 144 Hz) monitor screen connected to a Gigabyte computer was used to present the task. An Eye-Link Duo portable eye tracker (SR Research, Ontario, Canada) in the monocular remote setting was used to track the gaze position of a single eye according to the pupil and corneal reflections of an infrared light source. The sampling rate was 500 Hz. A small target sticker, placed on the child's forehead, was used to track the child's head position. The eye tracker was positioned along the midline of the screen that displayed the experiment. Participants were seated around 80 cm from the screen on their caregivers' lap or on a highchair. The camera to eye distance was set to about 50cm from the top of the screen. The eye tracking software was hosted on a Lenovo laptop. The experiment was monitored from another room via 2 wall-mounted cameras, one located just above the display monitor and another in the back of the room that captured the experiment as it was displayed to participants.

3.2.3 Stimuli

120 images were used as stimuli. Half of the images were of items likely to be familiar to infants in our age range. The other half of the images were of novel objects that infants would not have prior experience with. Familiar images were chosen to correspond to object names known by 50% of 18-month-old children according to OCDI norms from Wordbank (Frank et al. (2017); Floccia (2017) ,http://wordbank.stanford.edu). The novel images were selected from the NOUN database (Horst & Hout, 2016) and from an open source page (https://osf.io/49avs/). The pictures were processed and scaled using GIMP software (The GIMP Development Team, n.d.). The task was programmed using Experiment Builder (SR-Research, Ontario, Canada).

3.2.4 Procedure and design

Prior to the experiment, the procedure was described to parents and informed consent obtained in a waiting room. Parents also completed an optional demographic form. The experimenter then showed the parent and child into the experimental room. A video from Elmo's World (Sesame Street) was played while the parent placed the small target sticker on the participant's forehead. The eye tracker was then adjusted, and a five-point calibration sequence begun. Calibration used a looming black and white geometric shape presented in the middle, top, bottom, left, right and middle of the screen.

The procedure consisted of 48 trials, in 4 blocks of 12 trials each. Trials were divided into blocks so it would be possible to stop the experiment following the completion of any block to enable as many participants as possible to contribute data. Following successful calibration, the task started with the familiarisation stage. Participants were shown a video presenting each image that would be used in the subsequent block of trials so that all images were equally familiar and would have been seen once before the trials.

At the start of each trial (Figure 3.1), a memory array of two images was presented for 3000ms. This was followed by a probe image presented for 1000ms. On associated probe trials, the probe item was one of the two images presented on the just-prior slide. On random probe trials the item was an image not previously paired with any other image but previously seen during familiarisation. Following the probe, the test array was presented for a 3000ms response period. The two items in the test array were an item from the memory array (but not the associated probe), and another item not presented in the memory array. The item previously seen on the test array was designated the target, and the other item the distractor. The timings of slide presentations were based on a visual working memory study by (Ross-Sheehy & Eschman, 2019). At the end of each trial sequence a reward movie of a dancing cartoon character was presented on the side of the display that had previously contained the target image. This positive reward was always displayed, regardless of whether the toddler had looked at that location during the test slide. Between each trial a rainbow-coloured star was used as an attention getter to ensure participants were looking in the middle of the screen (OCDI, Ross-Sheehy & Eschman, 2019).

In each block, half of the trials included associated probes and half random probes. These factors were fully crossed with the novelty/familiarity of the stimuli to create the four trial types: familiar associated (FA), familiar random (FR), novel associated (NA), novel random (NR). In each block, trial orders were pseudo-randomly determined such that no more than two trials of a

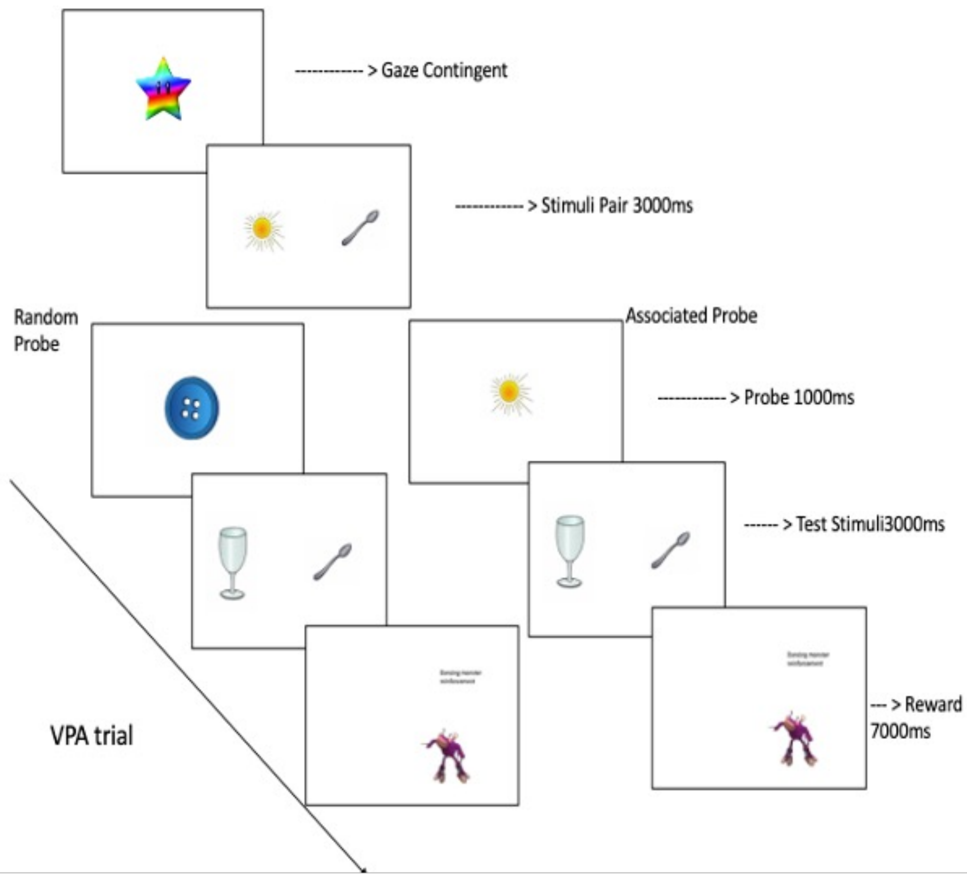

Figure 3.1: Order of events on one trial of the visual paired associates task

type occurred in a row. Two orders were created and counterbalanced across children.

After the task infants were given a small prize. Parents were emailed a link to the Oxford Communicative Development Inventory (OCDI, Hamilton et al., 2000) and asked to complete it within 15 days of their visit to the laboratory.

3.2.5 Analysis

Data Viewer software (SR-Research, Ontario, Canada) was used to extract the data from the 3000ms response period of the test array. Areas of interest (AOIs) were set to divide the whole screen in two halves with the objects in the middle. The raw gaze data from the Data Viewer sample reports were processed in R (R Core Team, 2017) using the eyetrackingR package (Forbes et al., 2021). During preprocessing we only included trials with more than 25% of looking data in analyses. EyetrackingR calculated the proportion of fixations on the target aggregated into 100ms time bins. Data were analysed with growth curve models Mirman (2014) using EyetrackingR.

We examined children's performance by total vocabulary score and also by a vocabulary percentile score that quantified how the number of words in each child's vocabulary compared to other children of their age and gender. To create these percentiles, we combined previously collected vocabulary data from studies in our lab (provide number) with data from Wordbank. The combined total vocabulary scores were used to calculate percentiles for each age and gender.

3.3 Results

This is the first visual paired associated task designed for use with very young children between 14 and 26 months of age and thus it is helpful to look at their engagement with the task. Every child completed some of each of the four types of trials. Table 3.1 presents the total mean and range of each type of trial completed after trackloss.

Table 3.1: Visual Paired Associates task, descriptives for types of trials

Type of trial	Mean number of trials	Range number of trials
Familiar associated (FA)	6.52	1-12
Familiar random (FR)	6.17	1-11
Novel associated (NA)	4.96	1-9
Novel random (NR)	5.46	1-12

We also carried out correlations between the number of trials completed and both age and vocabulary. The mean of children's productive vocabulary was 153 with a range of 2 to 381. Both correlations were non-significant, r = -.008, p = .1 for vocabulary and trials completed, and r = -.08, p = .83 for age and trials completed. Regressions examining the relation between the number of trials completed and the factors (novel/familiar & associated/random) revealed a significant effect of novel/familiar, $t(180) = -3.07$, $p < .01$, suggesting that children completed significantly fewer novel trials. There was no significant effect of associated/random, $t(180) = -0.68$, $p = .49$, and no significant interaction between the two factors, $t(180) = 1.18$, $p = .24$. These results suggest that children may have found the novel trials more challenging.

3.3.1 Looking Time Course

To look at the relation between visual paired associated memory and very early vocabulary development, specifically whether vocabulary size is linked to a child's ability to remember pairs of previously seen objects, we examined the time course of gaze dynamics on the test array according to participants' vocabulary size. The first analysis used total vocabulary as a predictor variable. However, because this work was motivated by a prior study that linked performance in a VPA task to vocabulary delay, we conducted an additional analysis using children's vocabulary percentile score as a predictor.

3.3.1.1 Analyses by vocabulary

The proportion of looks to the target out of total looking over the course of the response period is pictured in (Figure 3.2) & (Figure 3.3) and is separated for females and males as well as for high and low vocabulary groups based on an overall median split (visualisation purposes only). The object previously presented in the memory array was coded as the target on all trials. These data were examined with a series of linear mixed effects models using the glmmTMB function in the generalised mixed model TMB package (Brooks et al., 2017). We used cbind (SamplesInAOI, (SamplesTotal -SamplesInAOI)) to calculate the proportion looking to the target in each time bin. We then ran a beta-binomial model predicting the proportion of looking to the target by productive noun vocabulary (continuous), gender, associated/random probe, and familiar/novel stimuli as fixed effects. The random probe was effect coded as the baseline and the familiar /novel stimuli were contrast coded with familiar being the positive value. The linear, quadratic and cubic orthogonal time terms were also included as fixed effects based on visual inspection of the gaze trajectories. Subject and the orthogonal time terms were included as random effects.

Model comparison via an ANOVA showed that a model with gender fit the data significantly better compared to a model without gender, $\chi^2(40)$ = 138.81, p <.001. The full-time course model revealed a main effect of familiar/novel z = -8.01, p <.001 and a marginal effect of vocabulary z= 1.78, p= .08. There were two, two-way interactions of associated/random and familiar/novel z = 8.28, p <.001, and associated/random and vocabulary z = -4.99, p <.001. There were also a two, three-way interactions: one between familiar/novel, associated/random and gender, z = -2.45, p <.01, and one between familiar/novel, vocabulary and gender z = 4.77, p <.01. Lastly, there was a four-way interaction between familiar/novel, associated/random, vocabulary and gender z = -6.25, p <.001. There were also multiple interactions between these variables and the time terms (see Table 3.3). We did not have specific predictions about gender differences, but were interested in how target looking differs across the four trial types. Thus, we splitted the data by gender (see Figure 3.2 & Figure 3.3) and carried out simple effect model for the females and males separately.

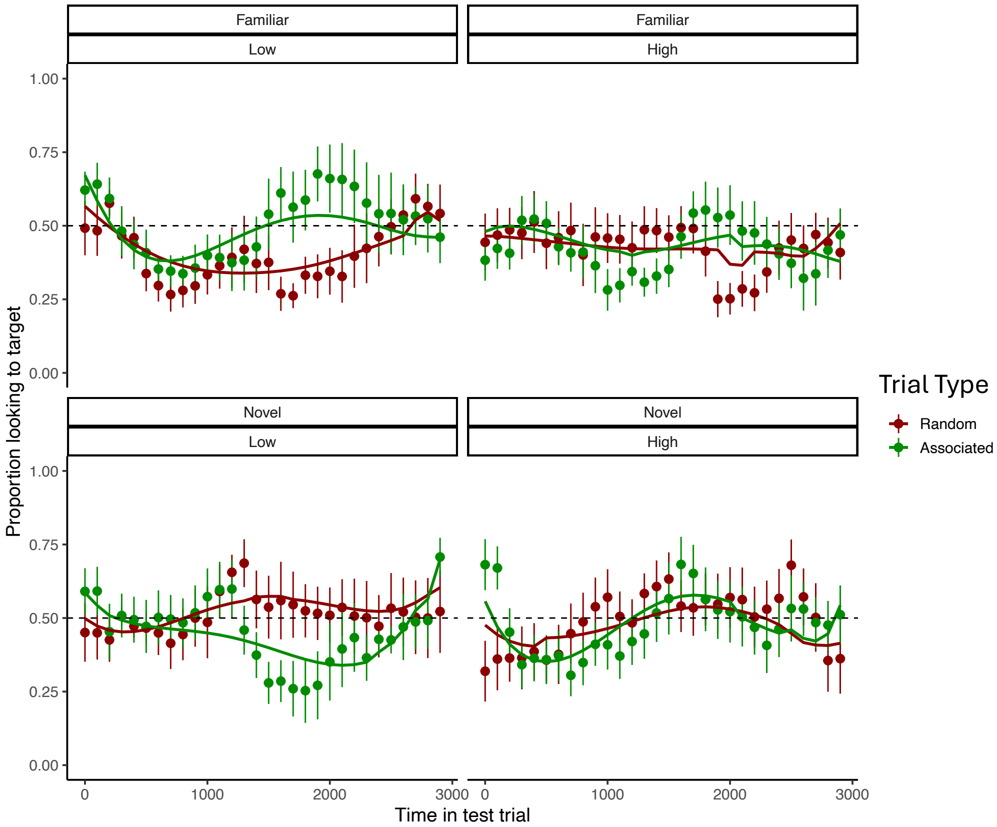

Figure 3.2: Relation between female children's looking to the target on trials with familiar (top) and novel (bottom) stimuli following associated (red) and random (green) probes with model predictions. The median split was used to split the data into low (left) and high (right) vocabulary groups for visualisation purposes.

The simple effects model on the data from females revealed a main effect of familiar/novel, z = -36.20, p <.001. There were also three significant, two-way interactions between associated/random and vocabulary z = 7.36, p <.001, associated/random and familiar/novel, z = 25.73, p<.001 and familiar/novel and vocabulary, z = 18.93, p <.001. There was also a three-way interaction between familiar/novel, associated/random and vocabulary, z = -27.70, p <.01 (Table 3.4). As can be seen in Figure 3.2, recalling that random trials were set as the baseline, on trails with familiar stimuli, it was clear that females with smaller vocabularies showed a small tendency to look more to the target following associated probes at the start of the trial and a clear preference for the

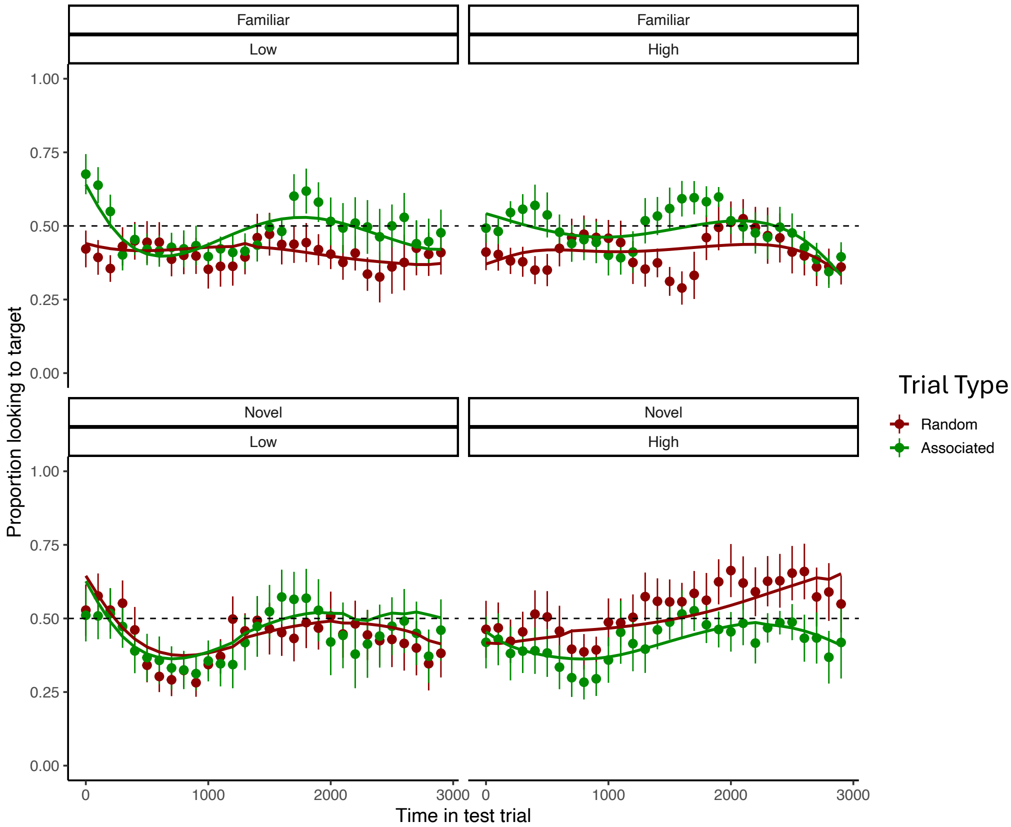

Figure 3.3: Relation between male children's looking to the target on trials with familiar (top) and novel (bottom) stimuli following associated (red) and random (green) probes with model predictions. The median split was used to split the data into low (left) and high (right) vocabulary groups for visualisation purposes.

target between approximately 1600-2100ms; looking to the target more than 50% of the time in this period. Females with larger vocabularies again showed a slight preference for the target at the start of the trial, and a stronger preference in the same later period, but this proportion did not go above 50%. In contrast, on trials with novel stimuli looking to the target following associated probes is only higher at the start of the trial, and interestingly, females with lower vocabularies looked away from the target in the middle of trials following associated probes. While all the objects were familiarised to the children prior to each block of the task, this looking to the distractor on random trails could indicate a preference for the relatively more novel object that was not seen on the memory array.

The simple effects model on the data from males revealed a significant main effect of familiar/novel, z = 13.67, p <.001 and associated/random z =-41.31,p <.001. There were also three significant two-way interactions, between associated/random and vocabulary, z = -24.18, p <.001, associated/random and familiar/novel, z = 39.97, p <.001 but also familiar/novel and vocabulary, z =-19.71, p <.001. There was also a three-way interaction between familiar/novel, associated/random and vocabulary, z = 24.25, p <.01 (Table 3.5). Similar to females, males with smaller vocabularies looked more to the target following associated probes at the start of the trial and again between approximately 1600-1900ms, that they looked to the target more than 50% of the time in this period. Males with larger vocabularies appeared to look to the target more, following associated probes in the same time periods. In contrast, for males with lower vocabularies looking on trials with novel stimuli looking to the target following associated probes was only higher at the middle of the trial, and interestingly, males with high vocabularies did not look more than 50% following associated probes (see Figure 3.3).

3.3.1.2 Cluster analysis grouped by vocabulary

The main analysis suggested that for both females and males, there was a tendency to look more to the target on familiar object trials following associated probe between 1600-2100ms. To test whether these differences were significant, we performed cluster-based permutation analyses Maris and Oostenveld (2007) using EyetrackingR. Specifically, we calculated infants' binarised proportion of target looks on familiar and novel trials within 100ms time bins during the response period for both associated and random probe trials. Monte Carlo permutations were then used to determine an appropriate significance level for the difference in target looking for trials with associated and random probes, given the number of participants and trials. Given that the pattern of significant effects was nearly identical for the simple-effects models on the data separated by gender (only differing by a significant main effect of associated/random for the males), we increased our power by not including gender as a factor in these analyses. The analysis revealed two potential divergences between looking following associated and random probes: between 0-300ms and between 1600-2100ms on trials with familiar stimuli for children with lower vocabulary levels. However, Monte Carlo simulations indicated that only the later time period reached significance, cluster t statistic = 7.98p = .111 for 0-300ms and cluster t statistic =13.69 p =.029 for 1600-2100 ms. Analysis for novel trials revealed no significant clusters for either low or high vocabulary groups. These cluster analyses provide some evidence that children who knew fewer words looked more to the target stimulus, following an associated probe item when the stimuli were familiar.

3.3.1.3 Analyses by vocabulary percentiles

The interactions with productive vocabulary score in the prior analyses suggest that children's ability to remember pairs of visual objects may be related to their vocabulary knowledge. To probe this possibility further, especially with an eye towards whether VPA performance may be related to delays in vocabulary development, we conducted a set of exploratory analyses examining performance in the task by children's vocabulary development percentiles. A model predicting target looking by the interactions of associated/random, familiar/novel and vocabulary percentile revealed significant main effects of associated/random, z = 2.04, p <.05 and familiar/novel, z = -5.95 p<.001 and two, two-way interactions between associated/random and familiar/novel z =

5.03, p<.001 and familiar/novel and percentiles z = 2.70, p <.01 (Table 3.6).

For visualisation we grouped the continuous percentile measure by those under (n = 9) versus above (n = 37) the 25th percentile, chosen to correspond to common classifications of children under the 25thpercentile for their age and gender as “late talkers” (Mourgues et al., 2016). As can be seen in Figure 3.4, the pattern of findings is similar to those based on total productive vocabulary. It is clear that children in below the 25th percentile looked more to the target following associated probes at the start of the trial and again between approximately 1200-2000ms, and that they looked to the target more than 50% of the time in this period. Children in the above 25th percentile appeared to look to the target more following associated probes only at the 1600 - 2000ms and they looked to the target more than 50% of the time in this period. In contrast, on trials with novel stimuli looking to the target following associated probes is only higher at the start of the trial, children above the 25th percentile looked towards the target at the 1600 - 2000ms of the trial following associated probes. Interestingly children in the interestingly below the 25th percentile looked away from the target in the middle of trials following associated probes.

3.3.1.4 Cluster analysis grouped by percentiles

We performed a cluster analysis on the data grouped by percentiles. Analyses on data from children below the 25th percentile on trials with familiar stimuli revealed no significant clusters. Children with vocabularies above the 25th percentile looked to the familiar target following associated probes significantly more than on trials with random probes between 1600 and 2100ms (cluster t statistic = 16.28, p <.01). On trials with novel stimuli, children below the 25th percentile revealed a marginal tendency to look away from the

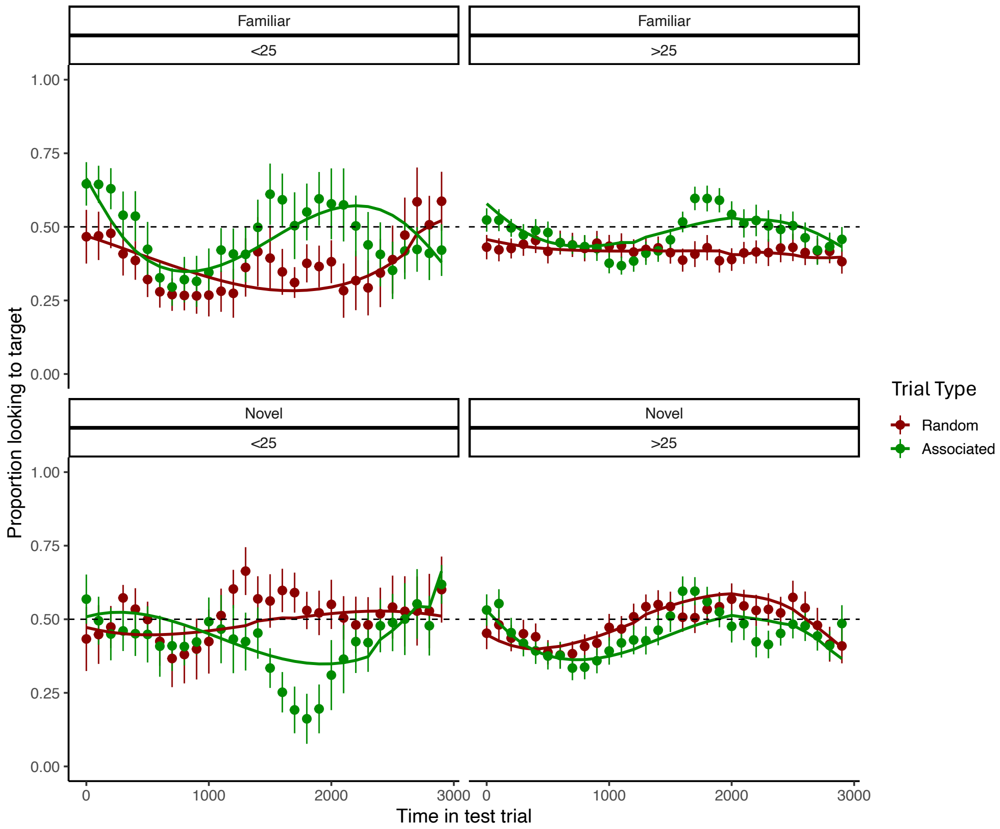

Figure 3.4: Relation between children's looking to the target on trials with familiar (top) and novel (bottom) stimuli following associated (red) and random (green) probes with model predictions. The percentiles were split. The data were split into <25th (top) and >25th (bottom) percentile for visualisation purposes.

target, towards the distractor, following associated probes between 1600 and 2000ms (cluster t statistic = -10.76, p= .06). No other significant clusters were revealed. These analyses must be treated with caution given the small numbers of children below the 25th percentile for vocabulary and the fact our percentile data were not based on a large validation study. Nevertheless, they provide some potential evidence on children's ability to remember which two familiar objects were previously seen together and were related to their vocabulary.

There is an interesting difference in the pattern of findings when total noun vocabulary versus vocabulary percentile is considered. When total noun

Table 3.2: Demographic information of the percentile and vocabulary groups

Percentile group	Vocabulary group	Gender	OCDI mean (range)	Age mean (Range)
Below the 25th percentile	Low	4 Males, 5 Females	20.2 (3-57)	21.4 (18-25)
Above the 25th percentile	Low	10 males, 4 females	56.5 (6-120)	18.4 (14-22)
Above the 25th percentile	High	12 males, 11 females	264 (127-381)	22.1 (18-15)

vocabulary is included in analyses children with *lower* vocabularies showed a significant preference to look at the target following associated probes on trials with familiar stimuli. However, when children's total vocabulary percentile is used in the analyses, children with *higher* percentiles showed a preference for the target on familiar trials following associated probes. Because percentile scores take into account both age and gender it is possible for children from the low vocabulary group to move to the high percentile group. Indeed, as seen in Table 3.2, some participants in the low vocabulary group are in the higher than 25th percentile group. Thus, it is possible the finding that children who knew fewer words look to the target more is driven by a group of children who are relatively high in total vocabulary for their age and gender. As can be seen in Figure 3.5, it is the case that the children classified in the low total vocabulary group but high percentile group show the cleanest pattern of more looking to the target on familiar object trials with associated probes. And, while there are clear qualitative similarities in the pattern of looking shown by the two sets of children that make up the low vocabulary group, it does appear possible that the low vocabulary children who are in the high percentile group may be driving the significant findings in the prior analyses.

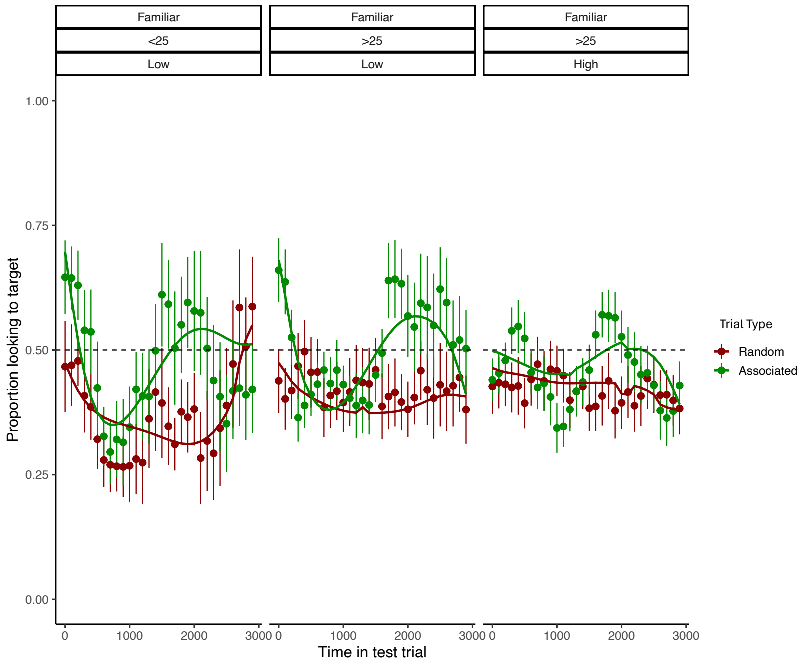

Figure 3.5: Relation between children's looking to the target on trials with familiar stimuli following associated (green) and random (red) probes with model predictions. The data were divided into low and high vocabulary groups using a median split and the percentile scores were split by the <25th and >25th percentile for visualisation purposes.

3.4 Discussion

The goal of this study was to investigate the relation between object memory and the very early stages of children's vocabulary development. To that aim, we collected data from an eye tracking visual paired associates memory (VPA) task involving children aged 15–24 months. We used statistical models to examine the relation between their vocabulary and their memory development with images of both familiar and novel objects. Overall, our findings provide some evidence of links between memory for visual stimuli and children's vocabulary development.

Our results indicate that children are better at remembering pairs of familiar objects than pairs of novel ones. This enhanced memory for familiar objects can be attributed to the fact that children are more likely to have established concepts and prior representations of these objects, making recall of the objects easier (when cued by the other item of the pair) than unfamiliar, novel, objects. However, it is also possible that established representations make it easier for children to store the pair of objects in memory. Given these possibilities, it could be either the storage or the retrieval of information from storage (or even both) that is better when children are confronted with familiar objects. Further, the difference in performance with familiar and novel objects does suggest our task is sensitive to differing levels of vocabulary knowledge, as we used likelihood of knowing the label as our measure of familiarity.

Contrary to previous research suggesting a positive correlation between paired-object memory and vocabulary size (Collisson et al., 2015; Vlach, 2016), our study indicated that children with smaller vocabularies tend to remember familiar objects more effectively than those with larger vocabularies. Children who had smaller vocabularies were more likely to demonstrate memory for the object that had previously been paired with the probe stimulus. This was an unexpected finding. One possible cause is that the children with larger vocabularies were seeking out the most interesting and novel object – the distractor – rather than the familiar, "paired" target. That is, children with larger vocabularies might have identified the target but because it was seen more recently during the memory array, they then looked away. In this way, they may have experienced a habituation effect (Poli et al., 2024; Shinskey & Munakata, 2010). Another possibility is that children with smaller vocabularies might rely more on visual and contextual cues to make associations, thus performing better in tasks that require remembering pairs of pictures (MacRoy-Higgins &

Montemarano, 2016). This is also because visual preference studies create a strong representation of familiar objects.

We used vocabulary percentiles to investigate this relation further. In particular, we looked at the data for children whose vocabulary was either above or below the 25^{th} percentile. In prior research, children below the 25^{th} percentile for their age and gender have been designated "late talkers" (MacRoy-Higgins & Montemarano, 2016; Perry, Kucker, et al., 2022). Prior research has found that some "late talkers" would continue to have vocabulary and language development difficulties and might later receive a diagnosis of developmental language disorder (DLD) (Bishop, 2017; McGregor, Goffman, Van, Hogan, & Finestack, 2020; Rescorla, 2011). In contrast to our unexpected finding about children with smaller vocabularies, when we looked at the data according to children's vocabulary percentile, we found that children whose vocabularies were above the 25^{th} percentile for their age and gender were able to remember what object had previously been seen with the cue on associated trials. Also, as a group, children below the 25th percentile did not perform as well. Thus, when the data were examined in this way, they fitted expectations better.

Interestingly, the pattern of results was slightly different when the data were analysed by vocabulary groups compared to percentile scores—it was the low total vocabulary group but the high percentile group that showed significant differences in looking to the target following associated probes. Indeed, when the low noun vocabulary group was divided into those who also had a low vocabulary percentile and those with a higher vocabulary percentile, it was the group of children who "filp" from low to high with the change in metric, who showed the cleanest pattern of results. This suggests the possibility that the VPA test we have developed might be most sensitive to detecting relations between children's relative vocabulary standing, rather than absolute number of words known, and memory for visual stimuli.

Furthermore, there are also arguments in this literature that total vocabulary score may not be the best measure of how performance relates to development. In particular, Kalashnikova, Escudero, and Kidd (2018) found that in a referent selection tasks that examined children's ability to remember newly-formed word-object mappings, having a larger vocabulary was more important than the specific words known. This was the case even when infants were familiar with the exact labels used in the referent selection and retention task. Kalashnikova et al. (2018) argue these outcomes suggest that as infants' vocabulary knowledge develops, they are also gaining more general abstract language knowledge that supports better and more robust mapping skills. This shows that children are benefited by the overall larger vocabulary rather than the specific vocabulary of each task, which can be seen in how the percentiles were formed in our results. The combination of the total vocabulary, age and gender as a whole to form these percentile show that there could be other factors than just total vocabulary by itself which influence children's memory for objects. This is seen in the different results we had when we used children's total vocabulary or percentiles.

The differences observed in the two measurements (percentile performance and vocabulary size) might suggest varied developmental trajectories and cognitive processes among children with different vocabulary sizes. This highlights the importance of considering vocabulary score, age and gender in language assessments. Vocabulary score might not always correlate with performance in tasks that rely heavily on immediate cognitive processing and contextual understanding. This finding aligns with previous research that emphasises the need for comprehensive language assessments that capture various dimensions of language use and cognitive processing (Bialystok, Peets, Yang, & Luk, 2010; Dockrell & Marshall, 2015). The fact that there are vocabulary differences when we use a cut-off that might indicate a child is at risk of later language delay, but not when you use a median split, suggests the possibility of a relation between memory for visual objects and word learning difficulties.

Our results that children with smaller vocabularies performed better on paired associate tasks are contrary to those of Vlach and DeBrock (2017) who explored the connection between visual paired associate learning and vocabulary development in preschool-aged children (22–66 months, mean age 47.81 months). They conducted two experiments: one on cross-situational word learning (CSWL) and another on paired associate memory tasks. Children were shown pictures and asked to match them, with their performance measured by the number of correct responses indicated by a pointing response. The study found that children with larger vocabularies performed better on both the CSWL task, learning more words, and on the VPA task, remembering which objects had previously been paired. Vlach and DeBrock (2017) concluded their study indicated a link between developing memory and word learning abilities. However, their finding that higher vocabulary children performed better in both tasks, contrasts with our find that children with lower vocabularies showed stronger object memory.

One difference between our study and that of Vlach and DeBrock (2017) is our use of eye tracking technology. Vlach and DeBrock (2017) asked children for a single discrete response for each trial—to point to the object that had previously been seen with the cue. Our method allowed us to track the children's visual attention over a longer time period on each trial, rather than assessing their specific choices at a fixed time after a question was asked. Eye tracking enables measurement of responses in a less demanding way for young children (Oakes, 2012). Thus, our task may have supported better performance from our youngest participants. Further, Vlach and DeBrock (2017) had a large age range in their study (22-66 months of age) and it is possible their significant effects were driven by children in the older part of their extensive age range (H. Vlach personal communication, April, 2017). Thus, the younger children might not have shown significant visual object memory. In this case then, it may be that use of preferential looking enabled our younger children to demonstrate abilities not demonstrable with the discrete pointing response.

Our results also appear to differ from those of Collisson et al. (2015) who found that children with more words in their vocabulary performed better on a paired associate task. This difference may stem from the difference in the stimuli used. Collisson et al. (2015) investigated the link between visual paired associates learning and vocabulary development in three to four-year-old children, including those with SLI. Children were presented with pairs consisting of a novel object and a visual symbol and instructed to remember them. During testing, they were presented with the symbol and asked to select the novel object that had previously been paired with it. The study found a significant correlation between the ability to remember which object was paired with which symbol and vocabulary development. Further, typical learners showed steady improvement and more correct responses over time, while the performance of children with SLI remained at chance level. Pairing symbols with pictures may be similar to pairing an object and a name which is more parallel with vocabulary knowledge learning. This might affect how children process and remember these elements. Our task was a bit different, as we used two images of objects, rather than one image and one symbol. This might be less like the word learning task of pairing an auditory symbol with an object. It is also possible, that using only pictures increased the task's complexity, as it is easier to confuse images, thus making them more challenging to recall.

Our results could be viewed as being consistent with previous research showing that before the age of 26 months, children find it difficult to form and maintain associations created after brief presentations. For example, previous studies have also indicated that children under 30 months struggle to remember new mappings between a novel object and a novel word and a novel object when presented only a handful of times (Bion et al., 2013; Horst & Samuelson, 2008; Kucker & Samuelson, 2012). This challenge in forming robust associations, either between two objects or between an object and a word, suggests a potential link between the task of adding new words to the vocabulary and memory development needed to maintain these associations, as observed in our research.

More generally, our research contributes to the body of work investigating how memory and language are related. Pickering et al. (2023) reviewed multiple studies and uncovered a notable link between the ability to remember pairs of visual stimuli and vocabulary development, similar to our own findings. The findings of Pickering fit with our study to the extent that children above the 25th percentile are better at remembering pairs of familiar objects than children below the 25th percentile. Overall, our models initially suggested positive effects for higher vocabulary score; however, a closer look suggested that children with lower scores were doing better. Pickering et al. (2023) demonstrated that individuals with better visual memory skills, especially in tasks involving the recall and recognition of visual pairs, tend to have more extensive vocabulary. They emphasise the importance of visual memory in the early stages of language acquisition. The implications of this research suggest that enhancing visual memory could significantly benefit vocabulary growth, particularly in early education settings. By focusing on improving visual memory, educators might provide children with the tools needed to better recognise and remember words, thus supporting overall language development. This approach underscores the importance of integrating visual learning strategies into early childhood education to effectively foster language acquisition and cognitive growth. Overall, our results fit with a growing literature showing connections between memory and vocabulary development or language learning (Reynolds, 2015; Vlach & Sandhofer, 2012).

3.4.1 Limitations and Future Directions

Our study represents an initial effort to examine relations between memory for visual objects and vocabulary development with an eye towards identifying which children, struggling with early word learning may catch up or are at risk of developing a developmental language disorder (DLD) in the future. This could also result in reading disabilities later in their development, as suggested by Henrichs et al. (2011), Rescorla (2011) and Snowling, Duff, Nash, and Hulme (2016). We found some potential evidence that for children who are late talkers, memory for pairs of objects might be lower. This might be a similar idea to the finding by Rose et al. (2004) who found that infants who exhibit weak visual recognition memory tend to also have less advanced language skills in later years. Also, there is a link between infant visual recognition memory and subsequent broad cognitive abilities. This relation suggests that early visual memory skills might be foundational for general cognitive development, including language acquisition, and executive functioning, as these skills help children to explore, remember and learn different objects. Consequently, early assessments of visual recognition memory in infants could potentially serve as predictors for future cognitive performance and developmental trajectories. Understanding children's ability to generalise and recall new words is crucial for understanding the multiple processes that influence children's word learning, illustrating the complex interplay of factors contributing to linguistic development.

Further research is needed to establish a clear link between VPA memory and language development. However, in future research using this task, we would recommend only including the familiar objects, based on the lack of significant effects indicating memory for pairs of novel visual objects. By focusing solely on familiar objects, we could more effectively investigate the relation between VPA memory and early vocabulary development by including more trials. While we did not find a relation between age or vocabulary and the number of trials completed, we did see that children overall completed fewer trials with novel stimuli. And while we were able to include more trials with familiar stimuli in the analyses, the mean number of familiar trials kept per participant was just over half. Thus, by dropping novel stimuli from the task, more familiar object trials could be included, potentially enabling more robust measurement of children's memory.

While we found some promising suggestions that performance on our VPA task might be different for children with lower versus higher vocabulary percentile scores, a number of additional steps would be required before this could be used to determine which children might best benefit from additional vocabulary learning support. One issue is that we found that children with lower percentiles did not demonstrate a significant preference to look at the object that had previously been paired with an associated probe. However, we had a small number of children in the lower percentile group. Thus, it is possible the null funding is due to insufficient power. One reason we might have had fewer children in the low percentile group is because our sample consisted mainly of children from high- and middle-income families. Future studies would benefit from including more children in the lower percentiles of vocabulary development for their age and gender; perhaps by including more children from lower-income households, as lower socioeconomic class has been related to slower vocabulary development (Hoff, 2003).

Finally, it could be useful in future work to analyse data from the memory array portion of the task. We have focused here on measuring whether children could demonstrate memory of the object that had been paired with an associated cue. However, to demonstrate such as memory children first need to form a robust encoding of the stimuli presented in the memory array. In a set of unreported analyses, we did examine whether looking to the target on the test array was influenced by how long children looked at the memory array overall. We did not find that looking on the test array was related to looking time on the memory array. However, a more detailed examination of looking focused perhaps on time spent on each object, may provide more insights because for children to build a memory for one object, they need to focus sustained attention on that object for a long period of time. Thus, it might be looking to individual objects, rather than total looking time at the array that matters.

3.5 Conclusion

Despite its limitations, this study examines the ability of children's object memory, very early vocabulary development and provides new insights into children, emphasising the importance of identifying potential difficulties at an earlier age in children's lives to provide support for them. This study revealed a significant link between visual paired memory and children's vocabulary, highlighting the importance of studying visual memory for understanding early vocabulary development and its impact on broader language development, which in turn affects later cognitive skills. Exploring this relation is a possible avenue for the early identification of late talkers that will not "catch-up" and bloom, however, will later be diagnosed with developmental language disorder (DLD), and particularly those who may face challenges later in school. Early identification enables the provision of support and interventions before these children start school, potentially enhancing their long-term educational outcomes and emphasising the significance of early detection in childhood language development.

3.6 Significance Tables

Table 3.3: Regression results for object memory by productive vocabulary and gender

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	-0.22	0.06	-3.56	0.00***
ot1	0.30	0.23	1.29	0.2
ot2	-0.15	0.22	-0.67	0.5
ot3	-0.44	0.25	-1.75	0.08.
ot4	0.02	0.23	0.08	0.94
Random_Associated	0.05	0.03	1.37	0.17
Fam_Novel_s	-0.39	0.05	-8.01	< .001***
OCDI_S_sc	0.11	0.06	1.78	0.08.
Gender_sc	0.02	0.12	0.15	0.88
ot1:Random_Associated	-0.17	0.19	-0.87	0.39
ot2:Random_Associated	0.41	0.19	2.19	0.03*
ot3:Random_Associated	-0.55	0.19	-2.89	0.00**
ot4:Random_Associated	0.31	0.19	1.61	0.11
ot1:Fam_Novel_s	-1.25	0.27	-4.63	0.00***
ot2:Fam_Novel_s	1.12	0.27	4.15	0.00***
ot3:Fam_Novel_s	0.63	0.27	2.34	0.02*
ot4:Fam_Novel_s	0.06	0.27	0.21	0.83
Random_Associated:Fam_Novel_s	0.57	0.07	8.28	0.00***
ot1:OCDI_S_sc	0.25	0.23	1.08	0.28
ot2:OCDI_S_sc	-0.46	0.22	-2.07	0.04*
ot3:OCDI_S_sc	0.03	0.25	0.12	0.9
ot4:OCDI_S_sc	-0.13	0.23	-0.56	0.57
Random_Associated:Fam_Novel_s:OCDI_S_sc	0.08	0.07	1.25	0.21
ot1:Random_Associated:Gender_sc	-0.44	0.38	-1.17	0.24
ot2:Random_Associated:Gender_sc	0.86	0.38	2.27	0.02*
ot3:Random_Associated:Gender_sc	-0.13	0.38	-0.35	0.73
ot4:Random_Associated:Gender_sc	-0.08	0.38	-0.22	0.83
ot1:Fam_Novel_s:Gender_sc	-0.3	0.54	-0.55	0.58
ot2:Fam_Novel_s:Gender_sc	1.94	0.54	3.59	0.00***
ot3:Fam_Novel_s:Gender_sc	-0.15	0.54	-0.29	0.77
ot4:Fam_Novel_s:Gender_sc	0.63	0.54	1.17	0.24
Random_Associated:Fam_Novel_s:Gender_sc	-0.33	0.14	-2.45	< .01*
ot1:OCDI_S_sc:Gender_sc	-0.92	0.47	-1.96	0.05.
ot2:OCDI_S_sc:Gender_sc	-0.85	0.44	-1.93	0.05.
ot3:OCDI_S_sc:Gender_sc	0.2	0.5	0.4	0.69
ot4:OCDI_S_sc:Gender_sc	0.08	0.46	0.18	0.86
Random_Associated:OCDI_S_sc:Gender_sc	0.12	0.07	1.83	0.07.
Fam_Novel_s:OCDI_S_sc:Gender_sc	0.46	0.1	4.77	< .01**
ot1:Random_Associated:Fam_Novel_s:OCDI_S_sc	-0.03	0.38	-0.08	0.94
ot2:Random_Associated:Fam_Novel_s:OCDI_S_sc	0.14	0.38	0.37	0.71
ot3:Random_Associated:Fam_Novel_s:OCDI_S_sc	1.66	0.38	4.38	0
ot4:Random_Associated:Fam_Novel_s:OCDI_S_sc	-0.45	0.38	-1.18	0.24
ot1:Random_Associated:Fam_Novel_s:Gender_sc	2.13	0.76	2.79	0.01**
ot2:Random_Associated:Fam_Novel_s:Gender_sc	-3.11	0.76	-4.09	0.00***
ot3:Random_Associated:Fam_Novel_s:Gender_sc	-1.82	0.76	-2.39	0.02*
ot4:Random_Associated:Fam_Novel_s:Gender_sc	-0.87	0.76	-1.14	0.25

Random_Associated:OCDI_S_sc	-0.17	0.03	-4.99	< .001***
Fam_Novel_s:OCDI_S_sc	-0.03	0.05	-0.60	0.55
ot1:Gender_sc	0.01	0.47	0.03	0.98
ot2:Gender_sc	-0.23	0.44	-0.53	0.60
ot3:Gender_sc	0.59	0.51	1.16	0.25
ot4:Gender_sc	-0.15	0.46	-0.32	0.75
Random_Associated:Gender_sc	0.02	0.07	0.26	0.8
Fam_Novel_s:Gender_sc	0.02	0.10	0.21	0.83
OCDI_S_sc:Gender_sc	-0.07	0.12	-0.56	0.58
ot1:Random_Associated:Fam_Novel_s	1.29	0.38	3.38	0.00***
ot2:Random_Associated:Fam_Novel_s	-1.29	0.38	-3.39	0.00***
ot3:Random_Associated:Fam_Novel_s	-1.19	0.38	-3.13	0.00***
ot4:Random_Associated:Fam_Novel_s	-0.72	0.38	-1.9	0.06.
ot1:Random_Associated:OCDI_S_sc	-0.06	0.19	-0.32	0.75
ot2:Random_Associated:OCDI_S_sc	0.04	0.19	0.19	0.85
ot3:Random_Associated:OCDI_S_sc	-0.09	0.19	-0.47	0.64
ot4:Random_Associated:OCDI_S_sc	0.01	0.19	0.06	0.95
ot1:Fam_Novel_s:OCDI_S_sc	-0.89	0.27	-3.29	0.00***
ot2:Fam_Novel_s:OCDI_S_sc	-0.12	0.27	-0.46	0.65
ot3:Fam_Novel_s:OCDI_S_sc	-0.37	0.27	-1.36	0.17
ot4:Fam_Novel_s:OCDI_S_sc	-0.1	0.27	-0.36	0.72
ot1:Random_Associated:OCDI_S_sc:Gender_sc	1.07	0.38	2.83	0.00***
ot2:Random_Associated:OCDI_S_sc:Gender_sc	0.69	0.38	1.84	0.07.
ot3:Random_Associated:OCDI_S_sc:Gender_sc	-0.66	0.38	-1.73	0.08.
ot4:Random_Associated:OCDI_S_sc:Gender_sc	0.22	0.38	0.58	0.56
ot1:Fam_Novel_s:OCDI_S_sc:Gender_sc	0.54	0.54	1	0.32
ot2:Fam_Novel_s:OCDI_S_sc:Gender_sc	-0.35	0.54	-0.65	0.51
ot3:Fam_Novel_s:OCDI_S_sc:Gender_sc	1.13	0.54	2.08	0.04*
ot4:Fam_Novel_s:OCDI_S_sc:Gender_sc	0.69	0.54	1.29	0.2
Random_Associated:Fam_Novel_s:OCDI_S_sc:Gender_sc	-0.85	0.14	-6.25	< .001***
ot1:Random_Associated:Fam_Novel_s:OCDI_S_sc:Gender_sc	-0.23	0.76	-0.3	0.76
ot2:Random_Associated:Fam_Novel_s:OCDI_S_sc:Gender_sc	0.40	0.76	0.52	0.6
ot3:Random_Associated:Fam_Novel_s:OCDI_S_sc:Gender_sc	0.28	0.76	0.37	0.71
ot4:Random_Associated:Fam_Novel_s:OCDI_S_sc:Gender_sc	-0.73	0.76	-0.97	0.33

*Note. Blank indicates p >.05, * indicates p <.05, ** indicates p <.01, *** indicates p <.001*

Table 3.4: Regression results for object memory by productive vocabulary for females

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	-0.2	0.06	-3.09	< .001***
ot1	-0.14	0.32	-0.42	0.68
ot2	-0.12	0.41	-0.28	0.78
ot3	-0.43	0.4	-1.08	0.28
ot4	0.05	0.32	0.15	0.88
Random_Associated	0.01	0.01	1.58	0.11
OCDI_S_sc	-0.02	0.06	-0.32	0.75
Fam_Novel_s	-0.32	0.01	-36.2	< .001***
ot1:Random_Associated	-0.09	0.03	-2.51	0.01*
ot2:Random_Associated	0.07	0.03	2.05	0.04*
ot3:Random_Associated	-0.31	0.03	-8.88	< .001***
ot4:Random_Associate	0.23	0.03	6.76	< .001***
ot1:OCDI_S_sc	-0.42	0.32	-1.31	0.19
ot2:OCDI_S_sc	-0.68	0.41	-1.66	0.1
ot3:OCDI_S_sc	-0.23	0.4	-0.58	0.56
ot4:OCDI_S_sc	-0.29	0.32	-0.9	0.37
Random_Associated:OCDI_S_sc	0.04	0.01	7.36	< .001***
ot1:Fam_Novel_s	-0.5	0.05	-9.9	< .001***
ot2:Fam_Novel_s	1.39	0.05	27.82	< .001***
ot3:Fam_Novel_s	0.32	0.05	6.4	< .001***
ot4:Fam_Novel_s	-0.26	0.05	-5.36	< .001***
Random_Associated:Fam_Novel_s	0.32	0.01	25.73	< .001***
OCDI_S_sc:Fam_Novel_s	0.16	0.01	18.93	< .001***
ot1:Random_Associated:OCDI_S_sc	0.45	0.03	13.15	< .001***
ot2:Random_Associated:OCDI_S_sc	-0.1	0.03	-2.89	< .001***
ot3:Random_Associated:OCDI_S_sc	-0.2	0.03	-6.05	< .001***
ot4:Random_Associated:OCDI_S_sc	-0.12	0.03	-3.44	< .001***
ot1:Random_Associated:Fam_Novel_s	0.08	0.07	1.14	0.26
ot2:Random_Associated:Fam_Novel_s	-1.54	0.07	-22.1	< .001***
ot3:Random_Associated:Fam_Novel_s	-1.13	0.07	-16.29	< .001***
ot4:Random_Associated:Fam_Novel_s	-0.56	0.07	-8.19	< .001***
ot1:OCDI_S_sc:Fam_Novel_s	0.21	0.05	4.43	< .001***
ot2:OCDI_S_sc:Fam_Novel_s	-0.33	0.05	-6.79	< .001***
ot3:OCDI_S_sc:Fam_Novel_s	0.64	0.05	13.49	< .001***
ot4:OCDI_S_sc:Fam_Novel_s	0.28	0.05	5.83	< .001***
Random_Associated:OCDI_S_sc:Fam_Novel_s	-0.33	0.01	-27.7	< .001***
ot1:Random_Associated:OCDI_S_sc:Fam_Novel_s	-1.21	0.07	-17.81	< .001***
ot2:Random_Associated:OCDI_S_sc:Fam_Novel_s	1.14	0.07	16.84	< .001***
ot3:Random_Associated:OCDI_S_sc:Fam_Novel_s	0.72	0.07	10.66	< .001***
ot4:Random_Associated:OCDI_S_sc:Fam_Novel_s	-1.1	0.07	-16.54	0.00***

*Note. Fixed effects are displayed including the Time term represented as ot1 (linear), ot2 (quadratic) and ot3 (cubic) Blank indicates *p<.05. **p<.01. ***p<.001.*

Table 3.5: Regression results for object memory by productive vocabulary for males

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	-0.23	0.05	-4.71	< .001***
ot1	0.21	0.21	1.03	0.3
ot2	0.11	0.23	0.47	0.63
ot3	-0.35	0.2	-1.72	0.08$^{\cdot}$
ot4	0.07	0.22	0.34	0.73
Random_Associated	0.07	0.01	13.67	< .001***
OCDI_S_sc	0.05	0.05	1.09	0.28
Fam_Novel_s	-0.3	0.01	-41.31	< .001***
ot1:Random_Associated	-0.07	0.03	-2.26	.02*
ot2:Random_Associated	0.02	0.03	0.75	0.45
ot3:Random_Associated	-0.65	0.03	-21.48	< .001***
ot4:Random_Associated	0.2	0.03	6.53	< .001***
ot1:OCDI_S_sc	0.63	0.21	3.04	< .001***
ot2:OCDI_S_sc	0.02	0.23	0.11	0.91
ot3:OCDI_S_sc	0.12	0.2	0.6	0.55
ot4:OCDI_S_sc	-0.14	0.22	-0.63	0.53
Random_Associated:OCDI_S_sc	-0.13	0.01	-24.18	< .001***
ot1:Fam_Novel_s	-0.93	0.04	-22.26	< .001***
ot2:Fam_Novel_s	-0.87	0.04	-20.82	< .001***
ot3:Fam_Novel_s	0.47	0.04	11.43	< .001***
ot4:Fam_Novel_s	-0.18	0.04	-4.26	< .001***
Random_Associated:Fam_Novel_s	0.43	0.01	39.97	< .001***
OCDI_S_sc:Fam_Novel_s	-0.15	0.01	-19.71	< .001***
ot1:Random_Associated:OCDI_S_sc	-0.69	0.03	-21.99	< .001***
ot2:Random_Associated:OCDI_S_sc	-0.07	0.03	-2.28	.02*
ot3:Random_Associated:OCDI_S_sc	-0.07	0.03	-2.31	.02*
ot4:Random_Associated:OCDI_S_sc	-0.15	0.03	-4.72	< .001***
ot1:Random_Associated:Fam_Novel_s	-0.03	0.06	-0.51	0.61
ot2:Random_Associated:Fam_Novel_s	0.32	0.06	5.27	< .001***
ot3:Random_Associated:Fam_Novel_s	-0.45	0.06	-7.55	< .001***
ot4:Random_Associated:Fam_Novel_s	0.19	0.06	3.23	< .001***
ot1:OCDI_S_sc:Fam_Novel_s	-0.76	0.04	-17.97	< .001***
ot2:OCDI_S_sc:Fam_Novel_s	0.01	0.04	0.3	0.76
ot3:OCDI_S_sc:Fam_Novel_s	-0.9	0.04	-21.57	< .001***
ot4:OCDI_S_sc:Fam_Novel_s	-0.05	0.04	-1.13	0.26
Random_Associated:OCDI_S_sc:Fam_Novel_s	0.26	0.01	24.25	< .001***
ot1:Random_Associated:OCDI_S_sc:Fam_Novel_s	0.44	0.06	7.02	< .001***
ot2:Random_Associated:OCDI_S_sc:Fam_Novel_s	0.04	0.06	0.68	0.5
ot3:Random_Associated:OCDI_S_sc:Fam_Novel_s	0.76	0.06	12.43	< .001***
ot4:Random_Associated:OCDI_S_sc:Fam_Novel_s	-0.23	0.06	-3.7	< .001***

*Note. Fixed effects are displayed including the Time term represented as ot1 (linear), ot2 (quadratic) and ot3 (cubic) Blank indicates *p<.05. **p<.01. ***p<.001.*

Table 3.6: Regression results for object memory with percentiles and gender

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	-0.28	0.13	-2.20	.03*
ot1	0.07	0.47	0.16	0.87
ot2	0.67	0.44	1.50	0.13
ot3	0.06	0.49	0.13	0.90
Random_Associated	0.14	0.07	2.04	.04*
Fam_Novel_s	-0.58	0.10	-5.95	< .001***
percentiles	0.00	0.00	0.47	0.64
ot1:Random_Associated	-0.44	0.38	-1.15	0.25
ot2:Random_Associated	-0.02	0.39	-0.06	0.95
ot3:Random_Associated	-0.64	0.38	-1.68	0.09
ot1:Fam_Novel_s	-0.79	0.54	-1.48	0.14
ot2:Fam_Novel_s	1.63	0.55	2.98	0.00**
ot3:Fam_Novel_s	0.71	0.54	1.32	0.19
Random_Associated:Fam_Novel_s	0.70	0.14	5.03	< .001***
ot1:percentiles	0.00	0.01	0.30	0.77
ot2:percentiles	-0.02	0.01	-2.23	.03*
ot3:percentiles	-0.01	0.01	-1.30	0.19
Random_Associated:percentiles	0.00	0.00	-1.38	0.17
Fam_Novel_s:percentiles	0.00	0.00	2.70	.01**
ot1:Random_Associated:Fam_Novel_s	1.96	0.77	2.55	.01**
ot2:Random_Associated:Fam_Novel_s	-2.34	0.77	-3.03	< .001***
ot3:Random_Associated:Fam_Novel_s	-3.91	0.76	-5.12	< .001***
ot1:Random_Associated:percentiles	0.01	0.01	1.08	0.28
ot2:Random_Associated:percentiles	0.01	0.01	1.28	0.20
ot3:Random_Associated:percentiles	0.00	0.01	0.29	0.78
ot1:Fam_Novel_s:percentiles	-0.01	0.01	-0.60	0.55
ot2:Fam_Novel_s:percentiles	-0.01	0.01	-1.42	0.16
ot3:Fam_Novel_s:percentiles	0.00	0.01	0.24	0.81
Random_Associated:Fam_Novel_s:percentiles	0.00	0.00	-1.26	0.21
ot1:Random_Associated:Fam_Novel_s:percentiles	-0.02	0.01	-1.36	0.17
ot2:Random_Associated:Fam_Novel_s:percentiles	0.02	0.01	1.97	.05*
ot3:Random_Associated:Fam_Novel_s:percentiles	0.05	0.01	4.23	< .001***

Note. Fixed effects are displayed including the Time term represented as ot1 (linear), ot2 (quadratic) and ot3 (cubic) Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Chapter 4

The relations between shape bias, children's vocabulary, visual attention, and memory at multiple timescales

4.1 Introduction

Early child's development is marked by changes in multiple cognitive processes; vocabulary grows (Samuelson & Smith, 1999), attention spans increase (Rose et al., 2009), and memory improves (Vlach & DeBrock, 2017, 2019; Spencer, 2020). Changes in these three cognitive processes are also interlinked. For example, children's early word learning development has previously been linked with their attentional abilities (Smolak et al., 2020; Kucker et al., 2023) as well as memory abilities at multiple timescales such as short- and long-term memory but also multiple modalities such as auditory and visual memory (Lum, Conti-Ramsden, Page, & Ullman, 2012). And clearly, adding a new word to their productive vocabulary requires children to go beyond finding the referent in the moment and then remembering the new word object mapping; it requires generalising to new instances of the named category. Thus, it is likely that memory and attention processes are also related to early noun generalisation. Indeed, one prominent bias children demonstrate when generalising novel nouns, the shape bias, has been suggested to be a memory bias (Vlach, 2016; Perry, Axelsson, & Horst, 2016). Here we examined the relation between the shape bias—children's tendency to attend to shape when generalising novel names for novel solid objects—and memory at multiple timescales.

The starting point for the study presented here is the findings presented in Chapter 2 (see also Bakopoulou et al., 2023). Recall that the study examined how novel words guided visual attention when children were asked to generalise novel names. The results replicated prior findings of attention to shape when generalising novel nouns and that "shape bias" was related to vocabulary development in two-year-old children with typical language development. We also found that after the naming event, children with larger vocabularies looked to the shape-matching test object more quickly than those with smaller vocabularies. And, while children looked equally at shape- and material-match test objects before the naming event, those with fewer nouns in their productive vocabulary showed more looks back and forth between the objects, suggesting that naming stimulated more comparison in children with smaller vocabularies. Overall, these findings align with previous studies by Smith et al. (2002) and Samuelson (2002), suggesting that differences in vocabulary size influence attention through a visual attention system that prioritises shape. The study in Chapter 2 makes the particular contribution of the first evidence that the naming event directly cues attention to shape in children who know more nouns.

One goal of the work in this chapter was to replicate the findings presented in Chapter 2. In addition, we seeked to examine how attention in the novel noun generalisation task relates to children's memory abilities. As reviewed in Chapter 2, one intriguing possibility regarding the fact that children who knew more words looked back and forth between objects less before making a generalisation decision, is that this could indicate they maintained stronger memories of the objects, supporting faster decision making. The study here examined this possibility by measuring children's working, short-term and long-term memory in addition to noun generalisation performance. The memory tasks used here focus on memory for visual objects, because a growing body of work has related development of the shape bias to development of visual object processing and recognition. Before detailing the tasks and measures collected here, we reviewed the relevant literature on the relation between visual object processing and the shape bias during the period of early vocabulary development.

4.1.1 Children's Recognition of Object Shape: Early Visual Processing and Vocabulary Development

When we look at the space around us, we perceive complex scenes that include foregrounds and backgrounds and surfaces and objects on those surfaces at various distances. As adults our perception of these components of the visual world is so automatic that it feels they are "given". However, research has shown that normal visual processing in humans is the result of a cascade of developmental processes dependent on early visual input, and that there are several "sensitive periods" during which lack of appropriate input causes disruption in processing (see Lewis & Maurer, 2005; Jayaraman &

Smith, 2020, for reviews). Building on this, a growing body of work shows that children's visual representation of object shape undergoes change between 12- and 36-months (see Smith, 2009) and that there are close ties between the development of children's visual object processing and vocabulary (Yee, Jones, & Smith, 2012; Slone et al., 2019).

As infants gain the ability to grasp and manipulate objects, they see varying perspectives of 3-dimensional items. This manipulation is dependent on the ability to sit up and hold an object. This is critical to the development of object perception because 3-dimensional views may be built from the dynamic experience of objects as they are rotated and manipulated (Farivar, 2009; Graf, 2006). Research has found that significant changes in visual object recognition occur during the period children rapidly expand their noun vocabulary, around 17- to 25-months of age (Pereira & Smith, 2009). Further, research suggests that better object exploration leads to stronger and more varied object representations which in turn may relate to differences in early vocabulary development (James et al., 2014; Slone et al., 2019). James et al. (2014) examined visual exploration in children and its impact on forming object representations. Thirty-six, 18- to 24-month-old children explored richly detailed toys, while wearing a head-mounted camera that recorded their visual perspectives. Children completed both an object exploration task and a subsequent object recognition task. In the object exploration task children explored rich and realistic toys representing four target categories. In the object recognition task, they were asked to identify a selected target by name between caricature targets and richly detailed targets. James et al. (2014) found that children's success in recognising sparse three-dimensional representations of the geometric shapes of objects as well as their vocabulary were related to their spontaneous choice of planar views of those objects during exploration.

This work underscores that object recognition is both implemented and updated through active visual exploration over early childhood and suggests a role for abstract representations of object shape in vocabulary development during the same period.

A study by Slone et al. (2019) similarly supports the connection between visual exploration, and vocabulary development. Slone et al. (2019) showed that active visual exploration in different contexts enhances object recognition. Using head-mounted eye tracking, the study tracked 15-month-old infants, as they played with objects and recorded the variability in the images of those objects from the infants' perspectives. Slone et al. (2019) found that infants who generated more variable visual images through manual manipulation of objects experienced greater vocabulary growth over the next six months. Importantly, it was the self-generated variability—created by infants actively manipulating objects—that predicted vocabulary growth, rather than variability caused by external factors such as parental manipulation.

Both the studies by Slone et al. (2019) and James et al. (2014) suggest that when children explore objects extensively it creates stronger mental representations, which enable faster and more accurate vocabulary acquisition. Therefore, the ability to remember objects and their associations during the toddler years is closely related to vocabulary development, emphasising the importance of both visual exploration and cognitive development in early language learning. Another link between early visual experience and language development comes from work suggesting that the visual statistics of an infant's surroundings—like the frequency and duration of object exposure—are critical predictors of their earliest spoken words. Clerkin, Hart, Rehg, Yu, and Smith (2017) investigated how infants' everyday visual experiences contribute to early word learning by analysing footage from head-mounted cameras worn by infants during mealtime. The study examined the frequency and types of objects in view. Despite the cluttered nature of these scenes, the researchers found that a small set of objects, such as tables, chairs, and cups, consistently appeared across multiple contexts. These high-frequency objects aligned with the first nouns typically learned by infants. Clerkin et al. (2017) suggested that the visual environment of an infant significantly impacts the vocabulary they develop. They concluded that this visual structure helps infants reduce referential ambiguity, making it easier for children to associate objects with their names, thus playing a crucial role in early word acquisition.

A final link between vocabulary and object representations comes from work suggesting that there is developmental change in toddlers' ability to recognise sparse representations of common objects and that this is linked to early vocabulary development. Smith (2003) focused on children's object recognition in two experiments examining young children's recognition of three-dimensional caricatures of the shapes of common things. In the first experiment, children's object recognition was measured in a non-linguistic play task and a name-comprehension task. In the second experiment, children were taught names for unfamiliar things, and then their recognition of caricatured versions of those things was tested. The stimuli included lifelike toy objects from 16 categories (e.g., hammer, boat, apple, chair), as well as three-dimensional caricatures of those same objects constructed from simple geometrical shapes. During the non-linguistic play task, children were shown 3 different objects and invited to play with them, with recognition based on whether a child looked like they knew what to do with the object (e.g. pretending it was a phone). During the name-comprehension task, children were asked to point to the named object out of a set of three. The researchers found that the more object names children had in their productive vocabularies, the better able they were to identify the stylised caricatures as objects. This indicates that category learning interfaces with vocabulary development, that is, as children learn more object names, they develop abstracted shape representations that enable recognising known categories from related but simplified physical representations. Further, a subsequent study showed that late talkers struggle to recognise the caricature stimuli, thus they demonstrate poorer object recognition; again supporting the argument of a relation between object recognition and vocabulary development (Jones & Smith, 2005).

Together this work supports arguments that the visual system and object recognition processes undergo substantial development in the timeframe when word learning is beginning and ramping up. Further, the work suggests developmental relations between object processing and vocabulary development. With respect to the aspects of early word learning that are the focus of this thesis, related work suggests that the development of the shape bias is preceded by changes in object processing and recognition (Yee et al., 2012). Yee et al. (2012), carried out two experiments, one large cross-sectional study and a smaller longitudinal study, that investigated the relation between visual object recognition and the shape bias. They tested 18- to 24-month-old children in novel noun generalisation, shape caricature recognition, and object recognition. They found that children's ability to recognise familiar objects from sparse shape representations developed before their ability to generalise novel nouns based on shape. Additionally, children with higher noun vocabulary recognised more shape caricatures and generalised novel nouns based on shape similarity more. This pattern was consistent across both the cross-sectional and longitudinal studies. The findings indicated a developmental trajectory where initial shifts in visual object recognition, which are associated with category learning, facilitated the identification of broader patterns within category structures.

Relations between vocabulary and object categorisation or perception are also seen in children with autism who do not seem to demonstrate a shape bias, even at the age of four (Tek et al., 2008; Potrzeba et al., 2015). Many children with ASD show atypical vocabulary development trajectories (Hart & Curtin, 2023). Children with ASD also struggle to categorise objects by similar features, using different and less typical grouping strategies, such as object functions (Naigles & Tek, 2017). In contrast to children developing vocabulary on a typical trajectory who often attend to similarity in shape, children with ASD struggle to categorise objects by similar features often focusing on minor details of objects rather than the global structure. However, there is some evidence that children with ASD who have larger vocabularies do attend to shape in some contexts and indeed show a shape bias in some tasks (Potrzeba et al., 2015).

Thus, the literature, including some work with children on atypical developmental trajectories, argues for a relation between early *visual* processing and vocabulary development and that children's attention to object shape is a critical basis for word mappings. For this reason, the study presented here focused on memory for visual stimuli and how children's ability to remember visual objects is related to vocabulary development. We built on the prior literature by examining the relation between the shape bias, memory for objects at multiple timescales, and early vocabulary development. In particular, we focused on long-term retention of new mappings formed in the novel noun generalisation task, object memory, and visual working memory. We reviewed relevant literature for each of these foci in turn.

4.1.2 Retention of newly learned word-referent mappings

Retention refers to the ability of children to hold and recall information over time, allowing individuals to recognise and categorise information beyond immediate or typical contexts. Retention is important in an individual's language development as it enables them to store and retrieve word-object pairings. Indeed, in order to demonstrate that a newly presented word-referent mapping has been learned, children need to show retention after a delay. However, retention is not always examined in studies of early word learning. This is somewhat surprising given that, as observed previously, the acquisition of words unfolds across multiple memory timescales, including in-the-moment mapping, retention and generalisation (Kucker et al., 2023). For example, many studies examining "fast-mapping"—children's ability to quickly map a novel word to a novel object (Carey, 2010; Carey & Bartlett, 1978)—look only at children's initial selection of a referent for a novel name, and not at whether this word-object mapping is retained after a delay (Horst & Samuelson, 2008, for review). This gap in the literature was addressed by Horst and Samuelson (2008) who conducted four tasks examining referent selection and word learning in 24-month-old infants. The tasks included both familiar and novel objects. Children were asked to pick the referents of several familiar and novel names and were tested for retention of the new word-object mappings followed a 5-minute delay. The study revealed children's proficiency in referent selection but difficulty with retaining novel words after a five-minute delay. Subsequent work has demonstrated that retention is booted if children are allowed to play with the objects before the referent selection trials (Kucker & Samuelson, 2012), and if the familiar objects present during referent selection are less well known (Kucker et al., 2018; Horst et al., 2011). This work has helped to elucidate the relation between in-the-moment mapping and longer-term retention (see Horst & Samuelson, 2008, for review).

Similar understanding is lacking for the mappings created during novel noun generalisation tasks. While much research has examined children's attention to shape when learning new nouns, and the relation of this attention to vocabulary, very little work has looked at children's retention of nouns presented in the NNG task. One exception is a study by Lorenz and Kucker (2021, April). These authors examined how exploration facilitates retention during a novel noun generalisation task. They included two conditions, one where children were familiarised with the objects ahead of every single trial and one in which no familiarisation was included. After 16 novel noun generalisation trials, Lorenz and Kucker (2021, April) asked 17- to 30-month-old children to complete 4 retention trials where children were presented with multiple exemplars at once and asked to find them by name (e.g., "Where is the kiv"). They found that overall children with larger count noun vocabularies chose the shape match in the initial noun generalisation trials. They also found that children who were familiarised with the stimuli before each NNG trial, were better at retaining the object names. Further, children who had larger count noun vocabularies also retained more words that children who had smaller count noun vocabularies.

The finding of more attention to shape with larger vocabulary is consistent with previous studies (Samuelson & Smith, 1999; Smith et al., 2002; Samuelson & Smith, 2000). Likewise, the finding of more retention following familiarisation is consistent with (Kucker & Samuelson, 2012) to the extent that children in the pre-familiarisation condition of that study retained more the novel word referent mappings. In the current study we added retention trials to our procedure from Chapter 2 in order to replicate the finding of retention following familiarisation (all our NNG trials include time to familiarise with the objects). We also examined how retention abilities are related to attention in the NNG task and to performance in our other memory measures.

4.1.3 Memory for visual objects and word learning

Research also suggests a role for object memory in early word learning. When new objects are presented, children must encode and remember them to recognise them later and to map them to words (Vlach & Sandhofer, 2012). Thus, visual object memory plays a crucial role in children's ability to learn and remember words for concrete objects. Children's ability to differentiate between objects seen before and new objects is critical to early word learning. This is because children tend to associate a new word with the most novel object present (Mather, 2013). Further, performance on cross-situational word learning tasks has been found to correlate with multiple object memory measures (Vlach & DeBrock, 2017).

Vlach and DeBrock (2017) explored how memory for objects supports word learning in cross-situational word learning (CSWL) tasks. They conducted two tasks: one involving a paired associates memory task and a CSWL task, both involving preschool-aged children. They also gathered data on a language task (the Peabody Picture Vocabulary Test). The memory task involved children being first trained on pairs of pictures presented on a screen. In the test that followed, children were shown a target picture and three choice options. The experimenter then asked the children to indicate which choice picture went with the target. They found a relation between children's performance on the task and their vocabulary size, children with more vocabulary showed better memory. The CSWL task involves the presentation of two objects and two words without indication of which word goes with which object. In the course of a number of such trials, however, the word that goes with a specific object is only said when the object is presented, allowing the correct mapping to be determined over multiple trials. Vlach and DeBrock (2017) also found that memory task performance was associated with CSWL performance. To the extent that learning words in CSWL requires combining information across separate presentations, this research suggests that the ability to remember objects across individual presentations is important for word learning and early language development.

Additionally, children with slow vocabulary growth (Jones & Smith, 2005), and those diagnosed with Specific Language Impairment (SLI) have been shown to preform differently on comprehension and novel noun generalisation tasks (Collisson et al., 2015). To further explore this, Collisson et al. (2015) tested children's ability to remember pairs of symbols and pictures. Half of the children tested had SLI and the other half were typical language learners; children were asked to remember a novel object paired with a novel symbol. In the test, the children were presented with two previously seen symbols on a laptop screen and asked to select the one that had previously been seen with a target image displayed at the top centre. Each symbol appeared once as a target and once as a foil. Children were presented with multiple learning and test trials for each symbol-image pair over multiple days of testing. Collisson et al. (2015) found that, the performance of typical learners steadily improved and they had more correct responses across the days of testing. Children with better memory for object pairs were also more likely to exhibit word learning biases beneficial for vocabulary growth. However, in the SLI group, performance stayed at chance even on the last day of testing. Further, children in the SLI group performed worse in the task involving pairs of novel symbols and objects compared to age-matched peers. Overall, children's ability to remember novel pairings of visual stimuli seems to be difficult for children with slow vocabulary development, in this case children with SLI.

Following this research, and particularly the findings Vlach and DeBrock (2017) and Collisson et al. (2015), we previously examined the relation between memory for pairs of visual objects and vocabulary (Chapter 3). Using a simple visual paired associates' task with eye tracking administered to toddlers between 14 and 25 months of age, we found evidence that young children could remember pairs of visual objects that were likely to be familiar. However, children did not demonstrate memory when novel objects were used in place of familiar ones. We also found that memory for objects was related to vocabulary development as we found that children with smaller vocabularies tend to remember familiar objects more effectively than those with larger vocabularies. The fact that it was children who knew fewer words that showed better object memory contrasts to prior findings indicating a positive relation between memory for visual objects and early word learning (Vlach & DeBrock, 2017, 2019). However, when we used a rough measure of children's vocabulary percentile in analyses comparing object memory and vocabulary, the results were in the expected direction; children with a higher percentile score showed better memory. Thus, in the current study we again tested children's object memory and examined its relation to vocabulary development via both raw productive vocabulary scores and percentiles, to see if our prior findings replicate. We also looked at how object memory relates to novel noun generalisation and retention of names presented in the NNG task.

4.1.4 Working memory and Word Learning

Working memory is a central cognitive system that actively holds information to facilitate cognitive operations (Spencer, 2020). It is responsible for storing, maintaining, updating and manipulating information (Baddeley, 2012;

Baddeley & Hitch, 1994), supporting complex cognitive behaviours and functions (Moser et al., 2018). In particular, Visual Working Memory (VWM) specifically refers to the capacity to temporarily store relevant visual objects in mind to enable retrieval to fulfil the requirements of ongoing cognitive tasks (Burnett Heyes, Zokaei, van der Staaij, Bays, & Husain, 2012; Pelphrey & Reznick, 2003). VWM is a cognitive system used by adults roughly 10,000 times every day in at least two different roles: comparing precepts that cannot be seen simultaneously and identifying changes in the environment as they occur (Luck & Vogel, 1997; Vogel, Woodman, & Luck, 2001; Buss, Fox, Boas, & Spencer, 2014). Furthermore, working memory retains and alters information for performing mental tasks. Spencer (2020) indicated that working memory provides a mental workspace for storing and manipulating information.

Behavioural studies indicate that the development of VWM begins in infancy and progresses throughout childhood (Fitch, Smith, Guillory, & Kaldy, 2016). VWM serves as an excellent marker of early cognitive development as it emerges early in life and can be used in infancy to predict later achievement (Rose, Feldman, & Jankowski, 2012). One task commonly used to study VWM is the change detection task (Feuerstahler, Luck, MacDonald, & Waller, 2019). According to Truong et al. (2022), this task assesses the capacity and functioning of VWM, offering insights into how well children can retain and detect changes in visual stimuli over time. In this task, children are initially presented with visual stimuli followed by a delay period during which the stimuli are no longer visible. During this retention interval, children are tasked with maintaining the visual information in their working memory. Following the retention interval a new display is presented, wherein some items have changed while others remain the same (Feldmann-Wüstefeld, 2021). Children then identify the items that have changed from the original presentation. Studies that have used the change detection task as a measure of VWM capacity have showed continued growth between 1.5 items at 3 years of age to adult-like capacity (4 items) by the age of 7 (Riggs, Simpson, & Potts, 2011; Simmering, 2012).

As infants cannot be asked the explicit question of item equivalence, a modified version of the change detection task is used to assess VWM capacity in infants—preferential looking change detection (VWM-PL Ross-Sheehy, Oakes, & Luck, 2003). VWM-PL is a simple task that isolates infant VWM from other factors. The VWM-PL uses two side-by-side blinking displays, each including an array of coloured squares (two, four, or six squares, for example). In one display, the items stay the same, whereas in the other display, the colour of one item changes. As participants cannot name the one that changes, eye tracking is used instead of asking them to make a response. The idea is that if children can retain the number of items shown in the display, they will remember from blink to blink which of the two displays is staying the same and which is changing and prefer to look at the changing display. Thus, the VWM-PL task measures the individual attentional focus of the length of fixation and frequency of shifting, specifically the first look change preference, fixation duration, and shift rate.

The VWM-PL task allows assessment of how accuracy in change detection varies with the number of items presented. As the set size (load), e.g., the number of items presented in each display, increases, children become less accurate at detecting changes (Riggs et al., 2011), reflecting the limited capacity of VWM. Accordingly, the change detection task provides evidence that VWM has limited capacity (Truong et al., 2022). Most children can only hold a relatively small number of visual items in their working memory at a time (Decarli, Piazza, & Izard, 2023). Further, a review by Buss, Ross-Sheehy, and Reynolds (2018)showed increase in VWM capacity from 6- to 12-months using the VWM change detection task (Ross-Sheehy et al., 2003; Oakes, Ross-Sheehy, & Luck, 2006). Thus, it is clear that VWM is changing as vocabulary development starts.

Other work suggests possible connections between VWM and language. Poorer VWM contributes to learning difficulties (Kudo, Lussier, & Swanson, 2015), including challenges in reading comprehension, mathematical problem-solving, note-taking, spatial reasoning, and multimodal learning (Kudo et al., 2015; Wiguna, Mh, Wr, Kaligis, & Belfer, 2012). VWM is essential for maintaining and processing visual information, such as words and illustrations. Accordingly, Bull, Espy, and Wiebe (2008) evaluated the establishment of VWM in infancy and early childhood. They tested 4-year-old children using cognitive batteries such as Short-term memory and working memory tasks, CorsiBlocks (forwards and backwards) and digit span. They also tested children's math and English outcomes. They also tested children's math and English outcomes. They found that children who had better digit span and executive function skills had an immediate head start in math and reading, maintained throughout the first three years of primary school. Visual-spatial short-term memory span predicted their math ability. Lastly, visual short-term and working memory predicted math achievement, while executive function skills predicted learning in general rather than learning in one specific domain. They noted that children with weak VWM struggled to hold the words they are currently reading in mind and often integrate these words with previously read ones. This difficulty leads to challenges in understanding and retaining content (Bull et al., 2008). It also hampers their reading comprehension skills and hinders literacy development.

Relatedly, Delgado Reyes, Wijeakumar, Magnotta, Forbes, and Spencer

(2020) suggested that working memory supports various aspects of language processing and production. For example, children rely heavily on working memory to understand complex words and sentences (Delgado Reyes et al., 2020). They temporarily hold and process words, phrases and grammatical structures in their working memory while reading and listening to a sentence (Delgado Reyes et al., 2020). Delgado Reyes et al.(2020)'s systematic review of fMRI studies highlights the intricate relation between linguistic abilities and WM functions. These results underscore the importance of WM in language processing and suggest that enhancing WM could potentially improve linguistic abilities. However, the exact mechanisms underlying this interaction remain to be fully elucidated. Working memory differences have also been seen in children struggling with language acquisition. Petruccelli et al. (2012) examined children with language impairment, resolved late-talkers and TD children in memory and language tasks. Following assessments of their working memory, Petruccelli et al. (2012) found distinct differences in the WM capacities of children with SLI compared to resolved late talkers and typically developing children.

Specifically, their findings showed that children with SLI exhibited significant deficits in both verbal and visuospatial WM tasks at 5 years old. This impairment was particularly evident in tasks requiring the storage and manipulation of phonological information. Resolved late talkers, on the other hand, demonstrated WM profiles more similar to those of their typically developing peers, suggesting that their earlier delays did not result in long-term WM deficits. Kidd, Arciuli, Christiansen, and Smithson (2023), also found that including verbal working memory along with vocabulary predicted later language development. Gray, Levy, Alt, Hogan, and Cowan (2022) also found that both auditory and visual working memory was a significant predictor of vocabulary development, as it explained a significant amount of word learning.

Thus, the literature provides support for the possibility of a relation between visual working memory and vocabulary development. This makes sense, given that visual working memory would serve to hold a representation of a visual object in mind while processing associated labels so they can be paired together. One goal of the current work is to examine possible relations between working memory, and visual working memory in particular, and early vocabulary development. Specifically, we investigated whether children's performance on a VWM-PL task is related to their demonstration of a shape bias, memory for new word-object mappings created in the novel noun generalisation task, and vocabulary. In addition, we examined relations between VWM and memory for pairs of objects as measured in the VPA task.

4.1.5 The Present Study

The current project builds on the premise that word learning is in fluenced by memory at multiple timescales. This project particularly focused on how children's visual attention to shape similarities in the novel noun generalisation tasks is related to retention and supported by multiple memory processes. We examined both visual working memory and longer-term object memory, as well as memory for new word-object mappings formed in the NNG task. In particular, children completed a novel noun generation task with eye tracking to measure their attention to shape, following Bakopoulou et al. (2023), but with retention trials added. Afterwards, they completed a visual working memory task and, as a measure of object memory, a visual paired associates (VPA) task similar to Chapter 3 but with no novel objects used as stimuli. We examined the relations between attention to shape, memory, and vocabulary measured both as raw number of words in the productive vocabulary and as a percentile relative to gender and age, so as to relate the findings to prior studies indicating that children struggling to build vocabulary show differences in the shape bias (Kucker et al., 2023; Perry, Kucker, et al., 2022).

For the NNG task, we hypothesised that there would be a positive relation between the number of nouns in the vocabulary and attention to shape during novel noun generalisation, based on our prior findings. Specifically, children who know many nouns would look equally to the two test objects before the naming event and quickly to the shape-match test object after. However, children who know fewer nouns would also look equally to the two test objects prior to the naming event, but these children would not look directly to the shape-match test object after naming. We predicted that, following the naming event and before choosing an object, children with lower vocabulary would transition between the objects more compared to children who know more words. Relatedly, reaction time to make a selection would be shorter for children with more nouns in the productive vocabulary. We also expected that children with more nouns in their vocabulary would retain more words than children with fewer nouns in their vocabulary. We predicted a positive association between visual working memory and vocabulary, if VWM does support early vocabulary development.

The relation between vocabulary and performance in our object memory task was more difficult to predict. The prior studies by Vlach and DeBrock (2017) and Collisson et al. (2015) would suggest a positive relation, with children who know more words remembering objects better. Likewise, in Chapter 3 we reported finding that children with a higher vocabulary percentile score for their age and gender showed better object memory performance. That contrasted with the findings using raw productive vocabulary score which revealed that children with smaller productive vocabularies showed better evidence of remembering the object pairs. Thus, the focus here would be on confirming the relation between vocabulary and object memory using our task, and how these results fit with the prior literature.

Likewise, predictions for the relations between our tasks were also more tentative. For NNG performance and retention, given that the shape bias is associated with more developed early noun vocabularies, and the words in a child's vocabulary are presumably ones the retain from prior presentations, we would expect that children who show a stronger shape bias would retain more of the names presented in the NNG task. Likewise, to the extent that the literature shows growth in VWM capacity in early infancy and toddlerhood, we might expect a positive relation between attention to shape in the NNG task and VWM performance as well as retention and VWM performance generally. In addition, and more specifically, if our prior finding that children with smaller noun vocabularies transitioned between objects more was due to their inability to remember the stimuli, we would expect to see a negative relation between VWM and the number of transitions between objects following the naming event. Lastly, visual working memory would also be related to faster responding in the NNG task.

Again, expectations related to performance in the object memory task depend on whether what we found when we compared object memory with vocabulary measured as raw number of words, was reported in the productive vocabulary or as a percentile score. However, assuming we found the relation expected based on the literature—better object memory with higher vocabulary/percentile score, we would predict positive relations between object memory, the shape bias, retention and visual working memory.

4.2 Method

4.2.1 Participants

We used the software program G*Power to conduct a power analysis (Faul, Erdfelder, Lang, & Buchner, 2007). Our goal was to obtain .8 power to detect an effect size of 0.20 at the standard .05 alpha error probability on the different tasks. Based on the findings in Bakopoulou et al. (2023), G*Power suggested we needed 50 participants. Power calculations based on the (Vlach & DeBrock, 2017) study, that used a task similar to our VPA and a correlation of 0.5 power, indicated 19 participants would be required. For the visual working memory task, we used the study by (Yoo & Yim, 2018) which reported a correlation of .48 between expressive vocabulary and verbal VW and we found that we would need 31 participants. Finally, for the visual working memory task, a study by Wilson, Andrews, Hogan, Wang, and Shum (2018) reported a correlation of -.64 between vocabulary and spatial working memory suggesting that we would need 16 participants. Taking into account all the above, we decided to aim for 50-60 participants to meet our target power. This range is based on the maximal number returned from our set of power analyses, but also allows for the potential need for additional participants in cases where children did not meet the inclusion criterion for a task and to balance gender.

We recruited 68, 18-26-month-old children (31 females, 96% white) from a medium-sized city in the East of the United Kingdom. This number is bigger than desired as children were not screened for vocabulary size before participation, so it allowed us to add a couple more participants hoping to get wide vocabulary range. An additional 2 children were excluded for a failure to complete any of the tasks. Participants had normal or corrected-to-normal vision.

Informed consent was obtained from the parents prior to the experiment. All children received a small prize for participation. This project received ethical approval from the ethics board of the University of East Anglia (Project ID: ETH2122-0275).

Because not every participant managed to reach the inclusion criterion for all four of the tasks (ENNG, Retention, VWM, VPA), the final number included in analyses differed across tasks. Out of the initial sample of 68 participants 11 did not meet the NNG inclusion criterion of a response on at least 8 of the 16 trials, leaving a final sample of 57 participants for the analysis (29 females). The inclusion criterion of a response on at least 1 of the 6 retention trials, which resulted in a final sample of 32 participants out of the 57 tested the retention analysis (16 females). Two participants became fussy and did not complete the VPA task, leaving a total of 66 participants for the analysis (29 females). One participant did not manage to complete the VWM task, leaving 67 participants in the analysis of that task (29 females). We provided information about the number of participants included in each analysis of task relations in the results section below.

Children's family language questionnaire data for 55 children was recorded. Table 4.1 provides vocabulary information for the full sample as well as subsamples included in each task and reports incidences of language delay in members of the child's family. The average age of the children in the full sample was approximately 22 months, ranging from 18 to 26 months across groups defined by family language history. The sample was roughly balanced between children whose parents did not report a family history of language delay (27) and those with a report of language delay a family member (26). Overall, there was not a large variation between the groups in age, vocabulary (across multiple measures) and mother's education. A one-way ANOVA found no statistical significance age for the, $F(4, 50) = .743$, $p= .49$, mother education $F(4, 50) = .162$, $p= .98$, total vocabulary, $F(4, 49) = .367$, $p= .83$,noun vocabulary, $F(4, 49) = .272$, $p= .90$, percentiles, $F(4, 49) = .711$, $p= .588$, or the percentage of nouns in the total vocabulary, $F(4, 49) = .701$, $p= .595$, for the groups based on family language history data. Note that the three analyses on vocabulary data in this set were each on 54 children due to missing vocabulary data for one child.

Table 4.1: Summary of sample family language history data

	Family Language History Data					
	Overall mean (range)	Parent language delay mean (range)	Siblings' language delay mean (range)	Extended family member language issue mean (range)	No family history mean (range)	No answer mean (range)
N (females)	55 (27)	14 (9)	7 (4)	5 (2)	27 (12)	2 (0)
Age in months	21.9 (18-26)	22.1 (18-25)	21.7 (20-23)	22.4 (18-26)	22 (18-21)	19.5 (18-26)
Total Vocabulary	170 (3-418)	195 (7-414)	160 (12-353)	144 (6-355)	168 (3-418)	140 (132-149)
Noun Vocabulary	90.9 (0-194)	107 (0-194)	85.1 (7-165)	74.6 (1-173)	87.8 (1-194)	80.5 (76-85)
Noun Vocabulary Percentage of Total Vocabulary	48.4 (0-68.6)	47.1 (0-68.6)	52.8 (37.5-61)	41.8 (16.7-59.7)	48.5 (0-64.8)	57.7 (51-64.4)
Percentiles	53.3 (0-100)	53.7 (4-100)	44.7 (4-84)	41.8 (8-71)	55.2 (0-100)	84.5 (71-98)
Mother's Education	4.98 (1-8)	4.57 (1-7)	4.86 (1-7)	5.2 (1-7)	5.19 (1-8)	5 (4-6)

4.2.2 Design

The study was carried out in 2 different days using a within-subjects design. On one of the days participants completed the Novel noun generalisation task and a retention task and on the other day the participants completed the visual paired associates task and a working memory task. Children completed either NNG and retention (n = 49) or VWM and VPA (n = 17) on their first visit, completing the alternative set of tasks on their second visit, approximately one-week later. We ran the NNG task first because we had found previously that it could be helpful to let children step away from the task and come back to it at another time, if they were finding it too difficult. By running it first, we had the option of coming back to it at the second session if needed. We did this for 4 children. In the second visit the children completed the VPA and VWM in random order. On the first day of the experiment, the procedure was explained to the parents, and they provided informed consent in a waiting area. They also filled out a demographic form (optional). Then, the experimenter led both parent and child into the experimental room for the tasks carried out that day. Following the first session, the parents were emailed a vocabulary checklist (OCDI) and a family history questionnaire. After the first session children were given a book and a t-shirt and at the end of the second session, they were given 5-pounds voucher as a reward.

4.2.3 Apparatus

The apparatus for the NNG task and retention tasks was similar to that described in Chapter 2, but a new wooden stage that could fit an EyeLink 1000 and a GoPro camera (Figure 4.1) was used. The bottom was 72cm x 30cm x 10cm and the camera box that sat on top was top 34.5cm x 18.5cm x 12.5cm. While the experiment presented the real 3-dimensional objects to the children, in order to record the detailed timings of events and children's gaze patterns during the task, the structure of the task was programmed in Experiment Builder (SR Research) on a Mac mini. A Hann spree display (1920x1080)

Figure 4.1: Podium stage used in the NNG Task.

out of sight of the child and parent but visible to the experimenter, was used to monitor the progression of the experiment by the experimenter. A keyboard was used to advance the trials during the experiment. The eye tracker ran in the monocular remote setting to track the gaze position of a single eye according to the pupil and corneal reflections of an infrared light source. The sampling rate was 500 Hz. A 45 cm x 60 cm foam board with 5 square holes cut out (Figure 4.2) was used for the calibration process.

The VPA and VWM tasks were conducted in a separate room using the same eye tracking setup. A 24-inch BenQ Zowie XL2430 (up to 144 Hz) monitor screen connected to a Mac mini and a Lenovo laptop that interfaced with the eye-tracking software in order to present the task, which was made using SR Research Experiment Builder. An Eye-Link Duo portable (SR Research, Ontario, Canada) eye tracker in the monocular remote setting was used to track the gaze position of a single eye according to the pupil and corneal reflections of an infrared light source. The sampling rate was 500 Hz. The screen, Mac mini and eye tracker were placed on the table in the experiment room. The Lenovo laptop, which controlled the tracker, was placed on a table in the control room. A sticker was also used and placed on the children's head for the tracker to find the children's eye. Figure 4.3 shows the setup for the

Figure 4.2: Calibration foam board used in NNG task.

experiment. The set-up also included 2 cameras on the ceiling, which viewed the back and side view of the session.

4.2.4 Stimuli

For the NNG and retention tasks, the familiar and novel objects used previously by Samuelson (2002) and in Chapter 2 were used again. Each of the four novel object sets contained an exemplar, two test objects, that were made from different material and colour but matched the exemplar in shape, and two test objects, that were different in colour and shape but matched in exemplar in material. The same four novel words, “Zup”,”Kiv”,”Fum” and “Mip”, used in Chapter 2 were used again.

A total of 140 images of familiar stimuli, selected from stock photos, were used for the VPA task. Of these, 84 were previously used in the experiment reported in Chapter 3, and 56 were new. To select the new images, we found words using Wordbank (Frank et al., 2017) that are known by at least 50% of

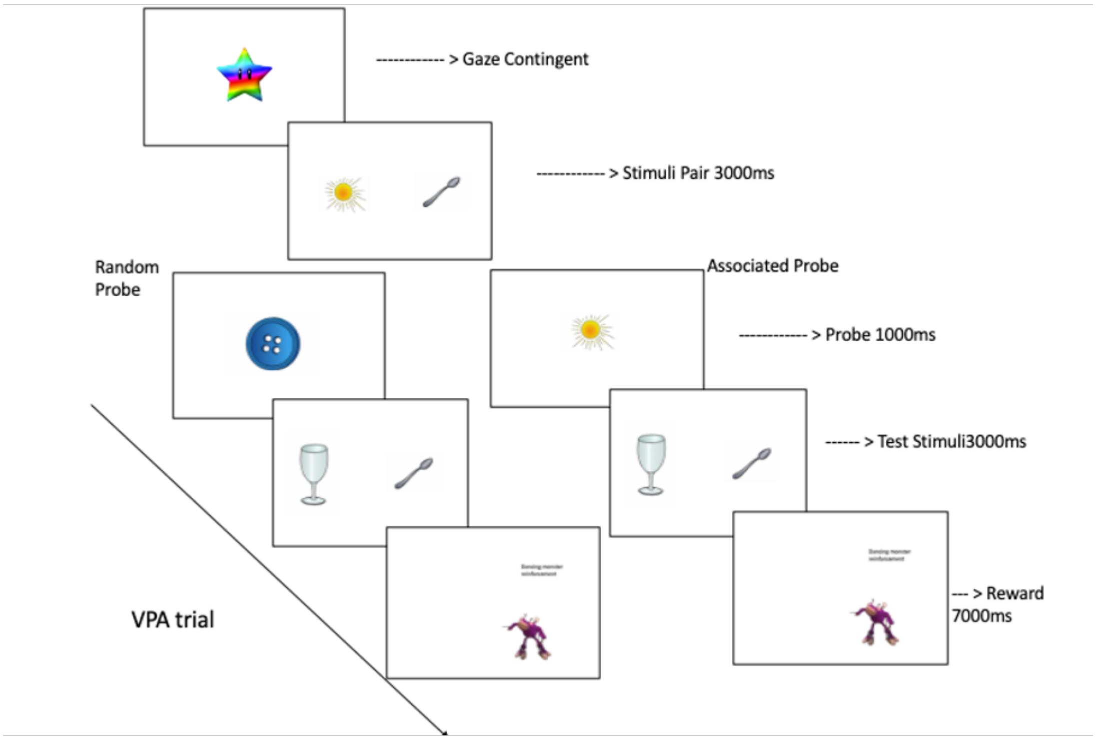

Figure 4.3: Order of events on one trial of the visual paired associats task.

18 months olds.

The stimuli for the VWM-PL task were small, coloured squares presented on two light grey rectangles. The background of the whole screen was dark grey. The colours of the squares were chosen randomly from a pool of nine: green, brown, black, violet, cyan, yellow, blue, red, and white.

4.2.5 Procedure

Testing sessions for NNG and retention began by allowing the child to play in the waiting area to familiarise themselves with the environment. A small target sticker was placed on infants' forehead, and they were guided into the experimental rooms. Each child sat either on a highchair (with the caregiver behind them) or on their caregiver's lap.

The procedure for the NNG task itself was as described in Chapter 2 with the main modification being the addition of a calibration procedure, prior to the warmup trials. A foam board was placed on the stage forming a plane perpendicular to the stage, at the position the exemplar and test objects would sit during the task. Five holes in the calibration board corresponded to the locations of each test object, and the exemplar, as well as the experimenter's face. To capture the children's attention, a plastic duck bath toy was used, appearing in different holes in a random order as determined by the computer. Following calibration, the familiar and novel trials proceeded in an identical format to that described in Chapter 2 (see Figure 2.3 from Chapter 3).

To examine retention, following a five-minute break after the standard ENNG trials, children were shown 2 of the exemplar objects for familiarisation. Then, the experimenter took the objects back and placed them on either side of the stage. The participants were then prompted with the name of one of the exemplar objects, e.g. "Where is the zup?". If the child did not reply, the experimenter, re-prompted another two times. A maximum of 6 retention trials were performed, pitting each exemplar object against another.

Testing sessions that included VPA and VWM began following the same format; the parent and child sat in the waiting area and the child again was allowed to play with some toys. At the same time, the experimenter provided the parent with some information about which task would be carried out that day. A small target sticker was placed on the infant's forehead, and they were guided into the experimental room. The child sat on a highchair (caregiver behind, off on the side) or on their caregiver's lap. The researcher positioned the participants as necessary to ensure they were in the best location and distance from the eye tracker. The calibration process began once the experimenter confirmed that the camera could capture the pupil and corneal reflection. Calibration involved displaying a black and white geometric shape at five different locations on the screen (middle, top, bottom, left, and right) to match the raw eye position data with the camera image data. This allowed for the mapping of gaze position to the stimulus presentation. This was carried out before each of the tasks. After successful calibration, the experiment began.

The VPA task described in Chapter 3 was used with the following five modifications. First, the novel trials were removed leaving only two trial types: Familiar Associated (FA), Familiar Random (FR). This modification was made because children in the study reported in Chapter 3 found the novel trials more difficult and we did not find evidence of memory on those trials. This enabled the second change of adding more familiar object trials in hopes it would increase the robustness of our measure. Secondly, a new set of 56 familiar words were selected from Wordbank on the basis that 50% of 18-month-old knew them and then stock photos were found to represent each word. This increased the total number of familiar trials to 40 in each order, compared to 24 in the previous task used in Chapter 3. Thirdly, rather than 2 blocks with familiar stimuli and 2 with novel, we used a repeating block structure. That is, the same object parings from blocks one and two were presented in blocks 3 and 4, but in in a randomised order. On the random probe trials in the later blocks, probes were altered to new objects on the second presentation to ensure no association between the probe and the pair was retained. Also, presentation of the target was counterbalanced – for half of the trials the target remained on the same side for presentation and test, the other half it switched. The fourth change made to the task was to make the familiarisation video gaze contingent and add a bounce movement and sound to the presentation of object. This was intended to increase participants' attention to the objects to better ensure familiarisation. Finally, the video played during setup was changed from *Elmo* to *Fantasia (1995)* Disney.

The VWM task was previously used by (Wijeakumar & Spencer, 2020) as well as others (Buss et al., 2018; Ross-Sheehy et al., 2003; Simmering, 2016), based on a VWM-PL task first developed by Ross-Sheehy et al. (2003). Figure 4.4 shows a schematic trial of load/set size 2. Two side-by-side flickering displays composed of an array of coloured 5cm by 5cm squares were shown for 10 seconds, with the squares visible for 500 milliseconds and off for 250 milliseconds. On one of the displays, one of the coloured squares changed colour at each flicker. An eye tracker measured children's looks to the changed square. The colours of the squares were chosen randomly from a pool of nine: green, brown, black, violet, cyan, yellow, blue, red, and white. The colours exhibited on a single display were always distinct from each other, but the same colour could be repeated across the two displays. The colour of the changing square was derived from the set of colours not currently present in that display. Each display consisted of either 2,4,6 (low, medium and high load respectively) set sizes. Set size and change side (right, left) were tested within subjects, creating 6 unique trial types. The task included 21 randomly selected trials 8 blocks (48 trials max; 16 of each SS), or until children lost interest or became fussy. The displays in which the coloured squares were presented were 21cm (h) by 29.5cm (w) in projected size, with a gap of the screen by 21 cm.

4.2.6 Data Processing, Coding and Analytical Approach

Vocabulary data was scored by counting the total number of words understood and produced as indicated by parents on the OCDI. In addition, to raw numbers of understood and produced words, we created percentile vocabulary scores in the same way as described in Chapter 3, using combined data

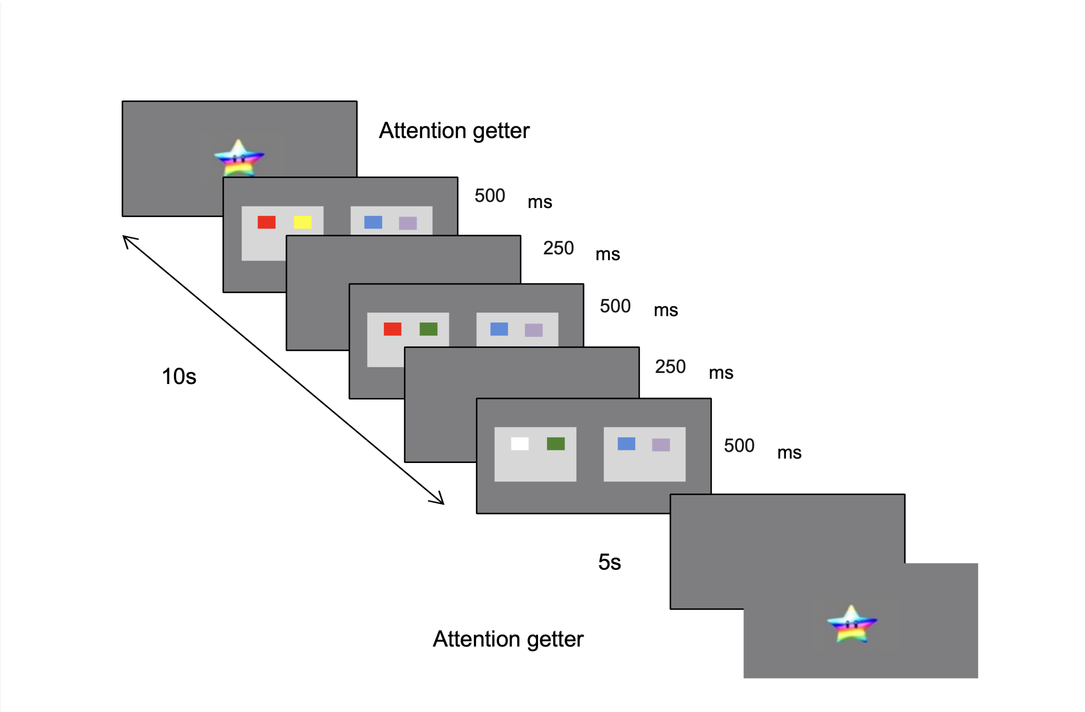

Figure 4.4: Order of events on one trial of the visual working memory task.

from our lab and WordBank (Saffran et al., 1996).

For all eye tracking tasks (NNG, VPA, VWM), Data Viewer software (SR-Research, Ontario, Canada) was used to extract the raw gaze position data, following the same process described in previous chapters. For the NNG task, areas of interest (AOIs) for each object in the display (exemplar, test object on the right, test object on the left) were defined as 60% bigger than stimulus on the screen to account for calibration errors and drifts in the eye tracker. The screen was split horizontally into 2 parts creating an "up" section with an AOI to capture looks to the exemplar/experimenter, and a bottom section that had AOIs capturing looks to the test objects on the right and left separately. We extracted data for the whole duration of the trial as we were interested to see children's looking for before the naming event but also after the naming event until when children made their choice. EyetrackingR (Forbes et al., 2021), was used to calculate the proportion of looks to the two test objects and "up" and "off" in each 100ms bin.

For VPA, the areas of interest for each object on the display were defined as the right and left halves of the screen in the same way as in Chapter 3. We used large AOIs to account for calibration errors and drifts in the eye tracker. Data were extracted for the full 3000ms response period of the test array for the VPA task. For VWM large AOIs defined as 60% bigger than the stimulus were used to account for calibration errors and drifts in the eye tracker. This AOI size was used to match prior work with this task (Aneja, 2022).

For all eye tracking data, Data Viewer sample reports of the raw gaze data were extracted and processed in R (R Core Team, 2017) using the eye trackingR package (Forbes et al., 2021). During preprocessing we excluded looks out of the AOIs and offscreen and only included trials with more than 25% of looking data in analyses. EyetrackingR calculated the proportion of fixations on the target aggregated into 100ms time bins. A custom R package ("DD-Lab" Package: Forbes et al. (2021)), was used to create Shift Rate scores for the VWM task.

Children's noun generalisation selections in NNG and retention selections were coded manually. For the NNG task we used the same behavioural coding as in Chapter 2. Data from all participants were coded for a basic and a choice response as described in that chapter. Retention performance was coded manually online during the session. When the prompt was said, the experimenter circled what the child picked or, if they did not pick anything, NR was noted.

Looking data from 18 participants was coded manually as described in Chapter 2 using DataVyu (DataVyu Team, 2014). These participants either refused to wear the sticker used by the eye tracker to track head position, became fussy during the experiment, or leaned too close to the tracker while pointing to indicate their response, resulting in loss of track that was not recovered. Data from the other 38 participants were obtained from the eye tracker. We checked that there was no difference between the participants whose data had to be hand-coded, and the rest of the sample. As can be seen in Table 4.2, these children were similar in vocabulary t (54) = -1.42, p = .16 and age $t(54)$ = .37, p = .72 to the rest of the sample. Also, they also had similar trial durations $t(54)$ = -.23, p =.82, as the rest of the sample.

Table 4.2: Summary of children's noun vocabulary, age and trial duration for hand-coded trials vs eye tracked

		Hand Coding	Eye tracked
Noun Vocabulary	Mean	70.71 (0-194)	99.23 (1-194)
	Median	22	22
Age in Months	Mean	22.17 (18-25)	21.90 (18-26)
	Median	22	22
Trial Duration	Mean	3.15 (0.77-10.70)	3.29 (0.76-8.26)
	Median	2.78	2.87

Twenty-five percent of the manually coded sessions were double coded for reliability with high agreement for all passes: 100% for trial breakdown, 98% for language sections, 100% for looks, 98% for children's touch and 100% for children's choices. Disagreements between coders were resolved by review of the coding manual and re-coding followed by joint review and discussion if disagreement persisted. In addition, as we used both eye tracking and hand coding, we checked that there were no discrepancies between the two different processes. We hand coded frame-by-frame looking of 3 participants that also had eye tracking data. We then calculated their proportion looks to the objects for each trial. The proportion of time looking to the test objects and exemplars only varied slightly between the two measures (see Table 4.3). A model showed that there were no differences between hand coding and eye tracking data, $t(18)$ = .03, p =.97.

NNG choice data and retention data were analysed with t-tests or ANOVA

Table 4.3: Proportion of children's looking to each test object by hand coded vs eyetracked during the entire trial duration

Proportion of looking to	Hand Coding	Eye tracked
Material-matching test object	0.23 (0.20-0.24)	0.23 (0.22-0.35)
Shape-matching test object	0.28 (0.19-0.34)	0.28 (0.21-0.43)
Exemplar test object	0.47 (0.43-0.55)	0.44 (0.43-0.45)

as appropriate. Eye tracking data were analysed with growth curve models (Mirman, 2014)(Mirman, 2014) using EyetrackingR. Specifics of analysis were reported in each results section, but in general, maximal models including participants and orthogonal terms as random effects were created first and simplified by ANOVA and comparison of AIC scores to determine the maximal supported model. When examining fixed effects, DHARMa (Hartig, 2022) was used for model comparison and verification.

4.3 Results

The aim of this study was to investigate the relations between the shape bias, children's vocabulary, visual attention, and memory. Towards this aim, we first reported individual analysis of the novel noun generalisation task including retention, the visual paired associates task and the visual working memory task. We then examined the relation between the different tasks.

Table 4.4 presents the total number of participants, trial count, mean and sd for the data used in the analysis. In the cases of VPA and VWM the mean number of trials was lower as children did not have to complete all the trials to be included in the dataset, and because trials with trackloss greater than 25 percent have been removed.

Table 4.4: Descriptive statistics for trial counts across the various tasks

Task	N	Total Trials in Analysis	Mean Trials per Participant (Possible Total Trials)	SD
NNG	56	728	13 (16)	2.83
VPA	57	1027	9.01 (40)	4.89
VWM	65	733	14.02 (48)	5.14

4.3.1 Novel Noun Generalisation

To calculate the proportion of shape and material choices in the NNG task, 74 "no response" trials were removed (9% of the data) from 29 different children with a max of seven trials from a single child. As in Chapter 2, We evaluated three hypotheses with respect to the data from the novel noun generalisation task; that shape responding would be positively related to the number of nouns in the productive vocabulary, that children who produced more nouns would look to the shape-matching test object more quickly after the naming event, and that children who produce fewer nouns will make more looking transitions between the test objects before making a generalisation decision. To do this, we examined three aspects of children's visual attention in the task: the time course of gaze dynamics to the exemplar and test objects before and after the naming event, children's looking transitions after the naming event, and differences in attention during the familiarisation period of each trial. We also assessed how these behaviours were related to productive noun vocabulary size, based on similar relations in prior studies (Samuelson & Smith, 1999).

4.3.1.1 Shape Choices and Vocabulary

First, we asked if children demonstrated a shape bias in their noun generalisations and whether this was related to vocabulary development. The current sample had a mean productive total vocabulary of 174.36 words, (*SD* = 138.54, *Median* = 131) and a mean total productive noun vocabulary of 90.57 words, (*SD* = 69.69, *Median* = 75.5). The analysis of noun generalisation choices was run on a total of 728 trials from 56 participants (*M*= 13 per child, *SD*= 2.83). A linear model was run predicting the proportion of shape choices by a full factorial of noun vocabulary (continuous, centred and scaled), gender, and stimulus set as independent variables including subject ID as random effect. Proportion shape choices were centred by subtracting 0.5 from all scores to enable comparison of the intercept to chance. Gender was not significant so it was removed from the model. Noun vocabulary included all words in the animals, vehicles, toys, food and drink, clothing, body parts, furniture and rooms, outside, and household items sections of the OCDI.

Stimulus set was significant. The mean shape choices for each set was above 50%; specifically, the means were: Fum 56%, Kiv 70%, Mip 60% and Zup 66%. This suggests some of the objects engender more attention to shape than others. No effect of set, using the same stimuli was found in Chapter 2, nor reported in a prior study using these stimuli (Samuelson, 2002). Given this, and the fact we had no specific hypothesis concerning differences between stimuli, stimulus set was removed from further models. The final model thus predicted proportion shape choices by noun vocabulary (continuous, centered and scaled). The intercept was significant, $t(54) = 5.95$, $p <.001$, suggesting an overall bias to attend to shape when generalising novel names (Table 4.6). There was also a significant main effect of vocabulary, $t(54) = 2.80$, $p <.01$, (see Figure 4.5). Consistent with previous studies including that reported in Chapter 2, children's tendency to select the shape-match object was linked to the number of nouns in their productive vocabulary.

Because some analyses in Chapter 3, and later in this chapter, used total

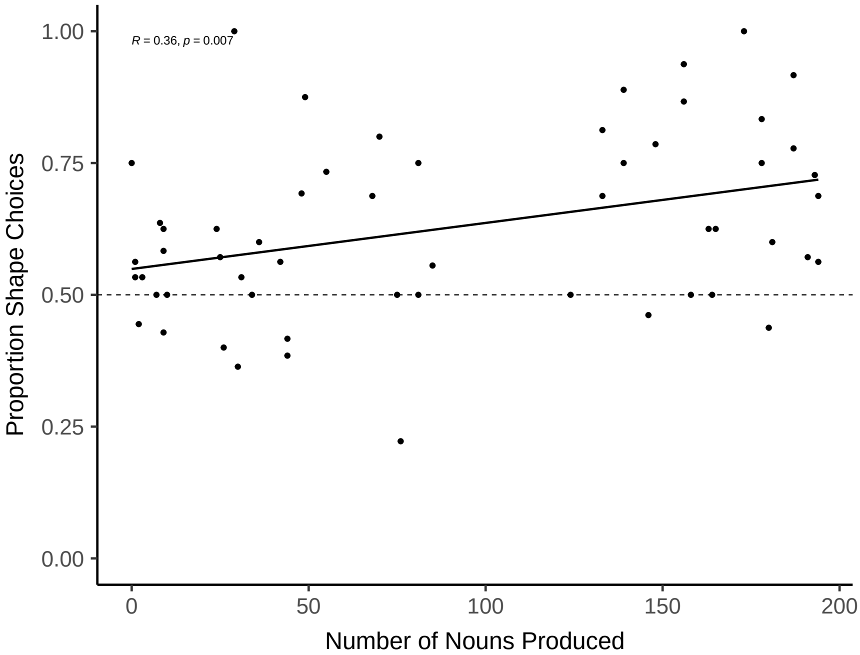

Figure 4.5: Proportion shape responding by productive noun vocabulary size. Solid line represents best fit linear regression. Dashed grey line represents chance level responding (.50).

vocabulary rather than noun vocabulary, we ran a second version of the final model using total vocabulary and found the same pattern of results. Productive vocabulary was a significant predictor, $t(53) = 2.85$, $p = .001$, and the Akaike's information criterion was -41.87 (Table 4.7). Further, we also examined the relation between shape responding and age. As we would be expected, noun vocabulary size and age were highly correlated in our sample, $R = .44$, $p < .001$. As before, the initial models included a full factorial of age, gender, stimulus set and set order as independent variables. Proportion shape choices was centred by subtracting 0.5 from all scores to enable comparison of the intercept to chance. Set order and the stimulus set used were not significant predictors and were removed. In the final model there was a marginal significant main effect of age $t(53) = 1.88$, $p = .06$ (Table 4.8). Akaike's information criterion was lower in the noun vocabulary model (-41.63) than in the age model (-37.57), suggesting that noun vocabulary provided a better fit.

As in Chapter 2, to compare to prior studies, we created Low (93 or fewer, M = 35.24, range 0-85, n=23) and High (94 or more, *M* = 161.3, range 104-194, n= 32) noun vocabulary groups using the same proportion of the total nouns on the OCDI, as Samuelson and Smith's (1999) 151 dividing point on the MBCDI. The mean age of the two vocabulary groups was significantly different, $t(51.71) = 3.95$, $p < .001$; Low $M = 20.94$ months and High M = 23.37. The High group made more shape choices, Welch Two Sample $t(49.14) = 2.93$, $p = .005$. However, the proportion shape choices was above chance (.50) for both the Low, $M = .57$, $t(31) = 2.64$, $p = .01$, and High $M = .70$, $t(23) = 6.03$, $p < .001$ groups. This replicates the findings reported in Chapter 2, that children with smaller vocabularies also generalised novel names by shape at above chance levels (see also Perry & Kucker, 2019).

4.3.1.2 Looking Time Course

Figure 4.6 shows the time course of looking before and after the naming event to the exemplar and test objects grouped by children's final generalisation selections and vocabulary level. The black line indicates word onset. As in Chapter 2, the "after" analysis window was 300ms from name onset (c.f., Fernald et al. (2008); grey bar) until a generalisation selection was coded. Because children were allowed to respond freely, this window varied. Maximum time of response was negatively correlated with vocabulary, $R = -.39$, $p < .001$, thus children with larger vocabularies took less time to generalise the novel noun. A linear model was carried out to examine differences in children's noun vocabulary scores between participants that were hand coded and the ones that we used eye tracking. The model predicted maximum time of response by noun vocabulary, and group (eye tracking or coding) as independent variables. The results revealed only vocabulary to be marginally significant $t(52)$ = -1.97, p = .05, suggesting again that the larger vocabulary children had the faster response times they had. Group was a non-significant variable $t(52)$ = .46, p= .65 suggesting that it did not influence children's performance on the task. Lastly, there was no significant interaction between noun productive vocabulary and group $t(52)$ = .14, p= .89 (Table 4.9).

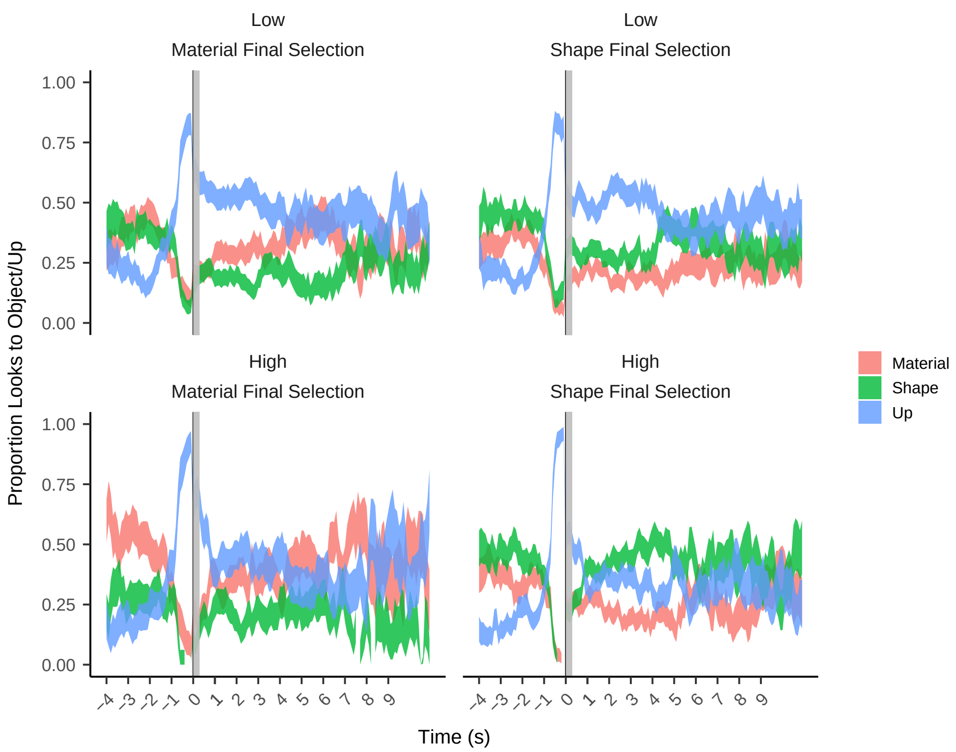

Figure 4.6: Average time course, across sets and trials, of looking to the shape- and material-match test objects and the exemplar for children with Low (<93) and High (>93) productive noun vocabulary groups. Data are grouped by trials ending in selection of the material-match (left) or shape-match (right) test object. Black line indicates the point in the naming event when the novel name was first said. Grey bar indicates beginning of the "after" analysis window. Note that grouping by vocabulary is for visualisation only; vocabulary was a continuous variable in analyses. The figure captures 62% and 77% of trials by the Low and High groups respectively.

Returning to the main analysis, all children looked to the shape- and material-match test objects before the naming event (see also Figure 4.6), but there were some differences based on vocabulary size and final selections. Specifically, lower vocabulary children who picked the material match, looked roughly equally to the objects before the naming event. However, the high vocabulary children, that chose the material test object, looked at the material test object more before the naming event. Notably, however, this was a smaller number of trials (36% material selections v 63% shape selections). For children who chose the shape test object both with lower and high vocabulary, they looked roughly equally to both shape and material test object before the naming event. All children looked up to the exemplar and experimenter when cued. When the name was said, children who had more nouns in their productive vocabularies looked to the shape-match test object on trials in which they selected the shape-match. These children looked to the experimenter slightly more than to the material matching test object on the smaller number of trials ending in a material selection. In contrast, children who had fewer nouns in their productive vocabulary looked longer to the exemplar, before shifting their attention to the object they eventually selected.

As in Chapter 2, we were unable to run growth curve models on the time course data because trial lengths varied across children. Thus, we calculated the proportion looking to the shape-matching test object out of the total looking to the test objects (Figure 4.7). We then ran separate generalised linear models with a beta-binomial link function on the before-naming and after-naming data, predicting the proportion by the interaction of vocabulary (continuous) and final selection with random intercepts for participants. The model of the before-naming data revealed no significant main effect of vocabulary or interactions involving this variable, all $|z'| < .50$, p <.01. The intercept was also not significant, z= . 74, p = .46, suggesting the proportions looking to the two objects was not different from 50% overall (Table 4.10). However, there was a main effect of final selection, z = 2.64, p = .01 suggesting that children looked more to the object they finally selected before the naming event Figure 4.7, this can also be seen in Figure 4.6). While the lack of a significant intercept suggested this effect minimal, the lack of vocabulary effect suggested it could be driven by the tendency of some children in both low and high vocabulary groups looking more to the shape-matching test object on trials that resulted in a shape selection (see individual data points in the graph, and right graphs in Figure 4.6). It should be noted that this effect was not seen in Chapter 3. We will return to this issue, and with the possibility that it is related to the timing of data collection for this Chapter and Chapter 2 relative to the COVID-19 pandemic, will be addressed in the general discussion.

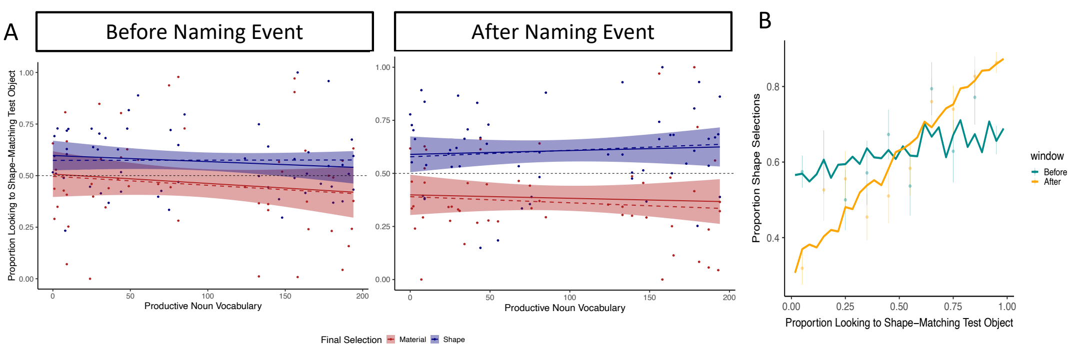

Figure 4.7: (A) Proportion looking to the shape-match test object by productive noun vocabulary size, before and after the naming event. Dashed coloured lines are model predicted data. Dashed black line indicates equal looking to the shape- and material-match test objects (.50). (B) Relation between looking to the shape-match test object before and after the naming event and selections of the shape-matching test object.

The model of the after-naming data revealed only a significant main effect of final selection, z = 5.73, p <.001 (Table 4.11). Follow-up models predicting proportion shape responding by vocabulary with random intercepts for participants on the data from trials ending in shape and material selections separately, revealed a significant intercept, z = 4.05, p <.001 for trials ending in shape selections, and the same significant intercept, z = -3.99 p <.001, for trials ending in material selections (Table 4.12 & Table 4.13) . This suggested that after the naming event children looked to the object they eventually selected for both shape and material selected trials. Finally, we examined whether looking before and after the naming event predicted children's choices (Figure 4.7B). Mixed-effect models with a binomial link predicting children's final selection by proportion looking to the shape-match test object revealed that looking both before z = 2.72, p <.01 and after z = 9.77, p <.001 the naming event, strongly predicted generalisation (Table 4.15). Also, after the naming event, but not before, there was a strong effect of vocabulary, z = 2.27, p = .02 (Table 4.14). Together then, even though the looking time course suggested that the naming event cued attention to the selected object, it is clear that children did sometimes look to the selected object before the naming event. Especially when this was the shape-match test object and when children had more nouns in their productive vocabularies. This is slightly different to what was found in main analysis reputed in Chapter 2, and the hypothesis that the naming event directly cued attention to shape. We will return to this issue at the discussion as it suggests that children who had the shape bias were influenced before the naming event and when the naming event was said they were directed to their choice.

4.3.1.3 Looking Transitions

To examine whether the naming event cued a deliberative comparison process similar to that reported in Chapter 2, we ran a series of linear models with a gamma link function predicting the number of transitions after the naming event by productive noun vocabulary and final selection. The model included where children were looking when the name occurred (at the exem-

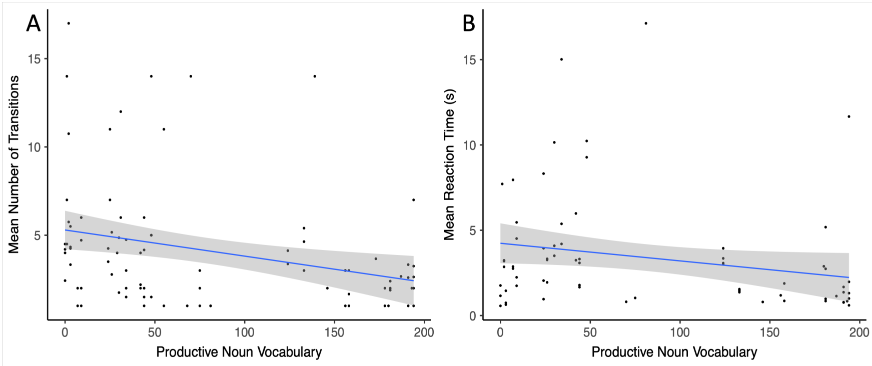

Figure 4.8: (A) Mean number of transitions by productive noun vocabulary size. (B) Mean reaction time by productive noun vocabulary size.

plar or off). Model comparison resulted in a final model predicting transitions by productive vocabulary (continuous) only, with a main effect of productive noun vocabulary, $z = -2.46$, $p < .01$, such that children with more vocabulary had fewer transitions between the test objects (Table 4.16). As can be seen in Figure 4.8A, the number of transitions decreased as vocabulary increased. This suggests the naming event stimulated more comparison of the objects in children with smaller vocabularies.

We also examined the "reaction time" to look at a test object after the naming event. This was defined as how long it took children to switch looking from the exemplar to the shape-or material-match test object on trials in which children were looking to the exemplar when the name was provided (77% of trials). Model comparison eliminated final selection and test object as predictors, leaving only noun vocabulary. No significant effects were found. As can be seen in Figure 4.8B, reaction time slightly decreased as vocabulary increased, but this change was limited (Table 4.17). This is different to what was found in Chapter 2 where there was a significant relation, with children who produced more nouns looking to the selected object more quickly and doing less comparison of the test objects, while those who produced fewer nouns compared the stimuli more.

4.3.1.4 Attention During Familiarisation

Finally, we investigated whether children had a more general bias to attend to the shape-match test object, by examining the proportion of time during the familiarisation period, children spent manually exploring the exemplar and test objects before the trial began. The mean length of familiarisation was between 10.14 – 328.89s, M = 36.12s and was not correlated with vocabulary (p=.40) or age (p=.20). The initial linear mixed-effects model included vocabulary (continuous) and final selection, but model comparison suggested a model containing only object (exemplar, shape-match, material-match) and random intercepts for participants was best. The model revealed a significant effect of object, $\chi^2(2) = 63.10$, p <.001 (Table 4.18). Children explored the two test objects equally and more than the exemplar (Figure 4.9). Thus, there is no evidence of a bias to attend to the shape-match test object prior to the naming event, in terms of children's manual exploration. Note this contrasted with the bias in favour of the eventually-selected object found in the looking data. To examine how attention during manual exploration was related to eventual object selections, we ran a general linear mixed-effects model predicting the proportion of shape choices by vocabulary and proportion of familiarisation time spent manually exploring each object in order to examine how children's exploration of the objects during the familiarisation period related to their noun generalisation. The final model we used revealed vocabulary to be a significant predictor suggesting that exploration of the objects during the familiarisation period was not related to children's choices but it was related to children's vocabulary in the noun generalisation task (Table 4.19).

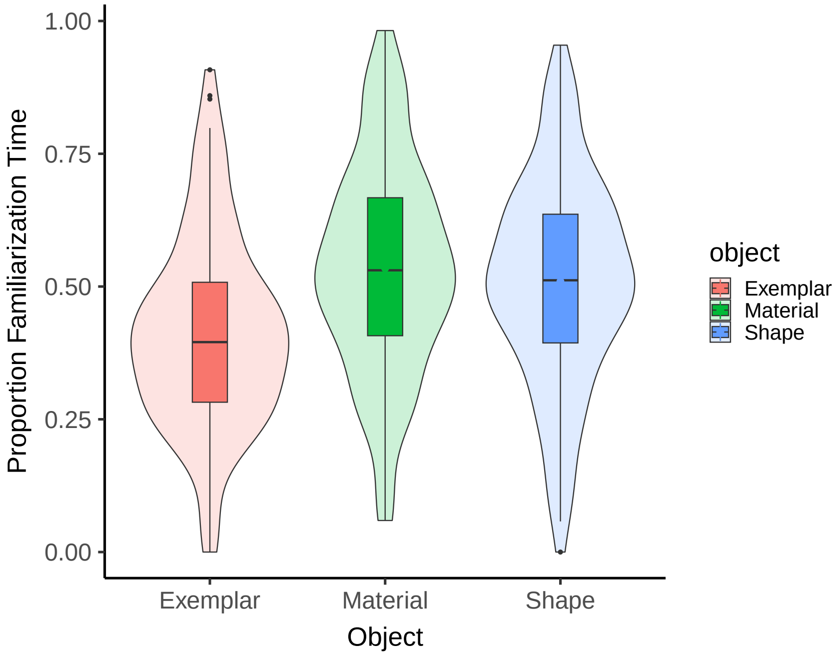

Figure 4.9: Proportion of familiarisation time spent exploring each object. Note that because children often touched or handled more than one object at once these proportions do not sum to 1.

4.3.2 Retention

To examine whether children retained the novel name-object mappings presented during the noun generalisation task we created percent correct scores for retention. These were the total number of correct selections of the named exemplar out of the total number of attempted retention trials. The mean percentage was 48% (0-100%) from the thirty-nine participants who completed an average of 4 retention trials (range 1-6; total of 156 across participants). There was no relation between the number of trials children completed and their vocabulary score, $r(37) = -.007$, $p = .99$ A one-way t-test against chance (50%) indicated no significant difference, $t(38) = -.46$, $p = .68$, suggesting that as a group, children failed to retain the names presented ostensively during the noun generalisation task. Also, the correlation between retention data and noun vocabulary revealed no relation $r(37) = -.24$, $p = .80$ as can be seen

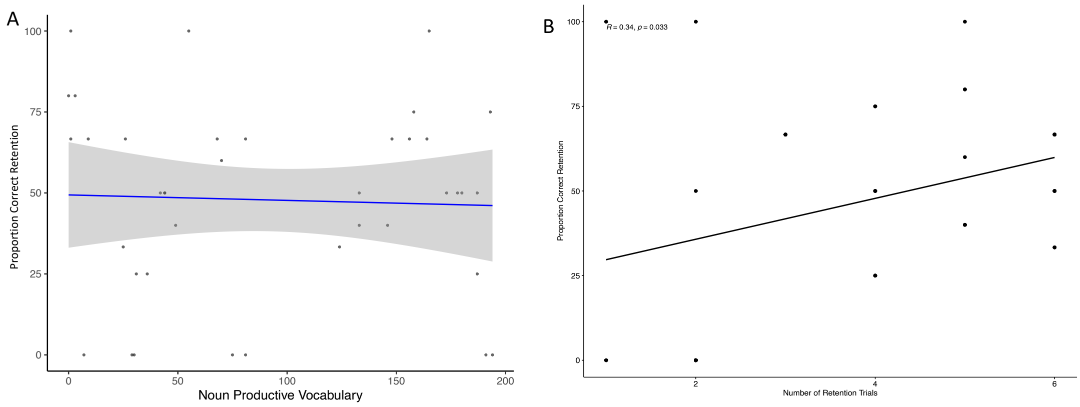

Figure 4.10: (A) Proportion correct retention by productive noun vocabulary size. (B) Proportion correct retention by number of retention trials.

in Figure 4.10. However, there was a significant correlation between proportion correct and the number of trials completed, $R = .34$, $p = .03$ such that children who did more trials got more of them correct. This suggests the possibility that willingness to do the trials may have been related to memory for the object names. Overall, however, these data did not suggest strong retention of the novel names presented in the ostensive context of the novel noun generalisation task.

4.3.3 Visual Paired Associates

The Visual Paired Associates task was designed to examine children's memory for pairs of objects, and via the collection of vocabulary reports from parents, how memory for objects might be related to vocabulary development. Based on the literature, the hypothesis was that children with more words in their vocabulary would create more robust memories for pairs of objects and they would look more to the target object following associated probes compared to random, indicating better memory. This hypothesis fitted with the finding reported in Chapter 3, that children with higher vocabulary percentiles had demonstrated better object memory. However, it is somewhat qualified by the fact we also found that by raw vocabulary score it was children with lower vocabularies who demonstrated better memory.

Children did not always complete all the trials in the task, and data from some trials were removed due to trackloss. The left two columns in Table 4.5 provide the mean and range of trials completed for each trial type (familiar associated, familiar random) and version (1, 2 differing in trial order). As it was evident children tended to complete only half of the trials presented in the task which was roughly the same as in Chapter 3.

We looked at the proportion of children's looking to the target using cbind (SamplesInAOI, (SamplesTotal -SamplesInAOI)) to calculate the proportion looking to the target in each time bin together with a hierarchical beta binomial model that included the effects of Trial Type (random, associated), Gender and OCDI (scaled and centred). The orthogonal time terms were included with the trial number and version as a random effect. This model revealed a significant effect of version. Examination of the versions revealed the two versions varied in the number of animate objects paired with inanimate objects across trials. Prior work suggests that animacy has a very strong effect on children's attention (DeLoache, Pickard, & LoBue, 2011; Simion, Regolin, & Bulf, 2008), thus we decided to remove trials that had an animate object paired with an inanimate object on the test slide. The right two columns of Table 4.5 give the mean number of trials completed, and the range, following removal of trials with mixed animate and inanimate stimuli. Unfortunately, this did remove a significant number of trials and meant we had low mean number of familiar random trials in version 1.

To examine performance on the remaining trials, cbind (SamplesInAOI, (SamplesTotal -SamplesInAOI)) was used to calculate the proportion looking to the target in each time bin. A beta-binomial model predicting the pro-

Table 4.5: Comparison of Participant Trial Completion: Mixed Animacy vs. Excluding Mixed Animacy Trials

Type of Trial	Mixed Animacy Trials		Excluding Mixed Animacy Trials	
	Mean Trials Completed	Range (Min-Max)	Mean Trials Completed	Range (Min-Max)
Familiar Associated (FA) Version 1	9.75	1-20	6.87	2-13
Familiar Random (FR) Version 1	9.38	1-20	3.00	1-6
Familiar Associated (FA) Version 2	8.21	1-18	6.32	1-13
Familiar Random (FR) Version 2	9.00	1-19	7.61	1-16

portion of looking to the target by productive noun vocabulary (continuous), gender and associated/random probe was run. The random probe was effect coded as the baseline. The linear, quadratic and cubic orthogonal time terms were also included as fixed and random effects based on visual inspection of the gaze trajectories along with subject as random effect. This model was used as it was found to better than one that also included both trial number and version. The model revealed a main effect of associated/random $z = 5.01$, $p <.001$. There were also interactions of associated/random and vocabulary $z = -3.48$, $p <.001$, and associated/random and gender $z = 2.97$, $p <.001$. There was also a three-way interaction between associated/random, vocabulary and gender $z = 2.47$, $p <.001$. The results also showed multiple interactions between the time terms and the variables (see Table 4.20).

As can be seen in Figure 4.11 and recalling that random trials were set as the baseline, it is clear that females with smaller vocabularies looked more to the target following associated probes between approximately 700-1000ms and they looked to the target more than 50% of the time in this period. Near the end of the trial, they again looked more to the target following an associated probe, but this proportion does not go above 50%. Females with larger vocabularies appear to look to the target more than 50% following associated probes near the end of the trial, approximately 2000-3000ms. In contrast, males with smaller vocabularies looked to the target following associated probes more and above 50% at the start of the trial around 220-500ms, and then at the end of the trial between approximately 2000-2800ms. Males with larger vocabularies looked more to the target following associated probes and at levels just below 50% between approximately 700-1000ms and then again around 2200-3000ms. Thus, there were some indications of looking to the target more after associated probes and potential relations to vocabulary. However, there was also some indication that children were looking back and forth between the objects. It is possible children's attention was somewhat drawn to the relatively more novel distractor object that was not seen on the memory array.

4.3.3.1 Cluster analysis

The main analysis the VPA data suggested that there was a tendency to look more to the target trials associated probe on various time points for both females and males. In order to test whether these differences were significant, we performed cluster-based permutation analyses (Maris & Oostenveld, 2007) using EyetrackingR. As in Chapter 3, we calculated infants' binarised proportion of target looks within 100ms time bins during the response period for both associated and random probe trials. Monte Carlo permutations were then used to determine an appropriate significance level for the difference in target looking for trials with associated and random probes, given the number of participants and trials.

This analysis did not reveal any clusters in looking following associated and random probes for low vocabulary females, even though in the graph

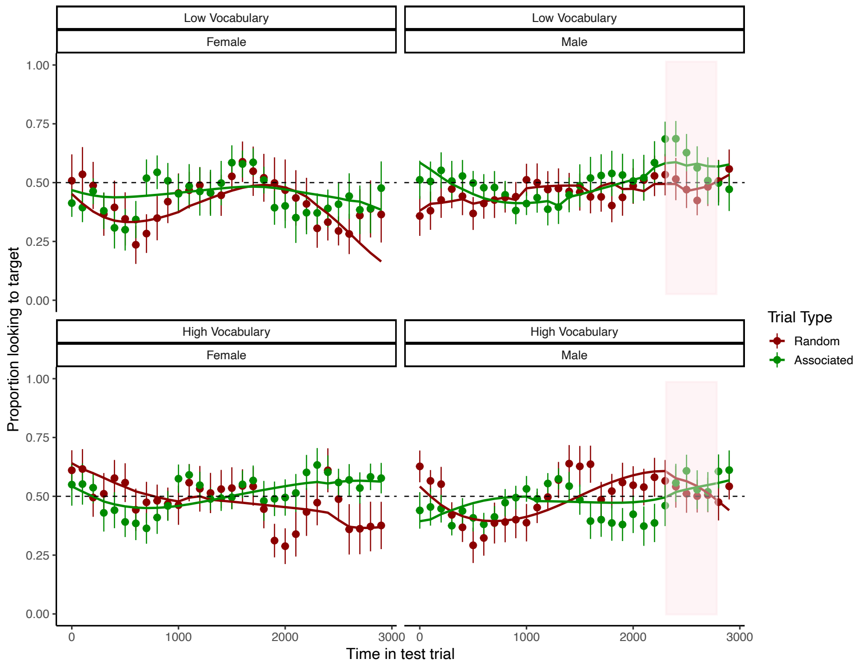

Figure 4.11: Relation between children's looking to the target on trials split for females (left) and males (right) following associated (red) and random (green) probes with model predictions. The median split was used to split the data into low (top) and high (bottom) vocabulary groups for visualisation purposes.

there seemed to be a small visual difference between associated and random trials. For high vocabulary females there was a non-significantly different cluster t statistic = 5.46, p = .29 between 1900-2100 ms. For males with smaller vocabularies the cluster analysis did reveal a significant difference in looking to the target following associated and random probes between 2300-2700 ms, cluster t statistic =11.12 p =.05, but the other potential cluster did not reach significance, 200-300 ms, cluster t statistic = 2.49 p =.42. Analysis of possible clusters for males with higher vocabularies revealed one cluster between 1600-1700 ms, that was non-significant, cluster t statistic = -2.20, p = .54. Thus, these analyses suggested only males with lower vocabularies looked significantly more to the target following associated probes.

The significant three-way interaction between vocabulary score suggested that children's capability to remember pairs of visual objects, as recorded in the task might be linked to their vocabulary knowledge, like the findings in Chapter 3. Thus, we explored whether children's performance in the task was related to their vocabulary development percentiles. Children were grouped into those in the lower 25th percentile for vocabulary (n = 18) and those above the 25th percentile for vocabulary (n = 39). A beta-binomial model predicting the proportion of looking to the target by children's percentiles (continuous), gender and associated/random probe was run. The random probe was effect coded as the baseline. The linear, quadratic and cubic orthogonal time terms were also included as fixed effects based on visual inspection of the gaze trajectories. Subject and the orthogonal time terms were included as random effects. The model revealed a significant main effect of associated/random, $z = 6.36$, $p < .001$ and marginal main effect of percentile $z = 1.80$, $p < .07$. There was also a two-way interaction between associated/random and percentile $z = -4.70$, $p < .001$ and a 3-way interaction between associated/random, percentile and gender $z = 3.85$, $p < .001$.

As can be seen in Figure 4.12, females below the 25th percentile in vocabulary looked more to the target following associated probes at the end of the trial between approximately 1800-3000ms, but this proportion did not go above 50%. Similarly, females above the 25th percentile looked more to the target following associated probes between 1000- 1800ms and between 2000-3000ms, although the second time period appeared to be at chance level. Males below the 25th percentile appeared to have looked to the target more, following associated probes at the start of the trial between 0-800ms, and from approximately 1200-3000ms, with both of these periods being above 50%. Males above the 25th percentile looked to the target more, following associated probes from 800-1000ms, but this proportion did not go above 50%.

Again, these data provided some suggestion of more looking to the target following associated probes for some children at some points of the trial. However, they again suggested a pattern of looking back and forth between the objects, and potentially some interest in the relatively more novel distractor.

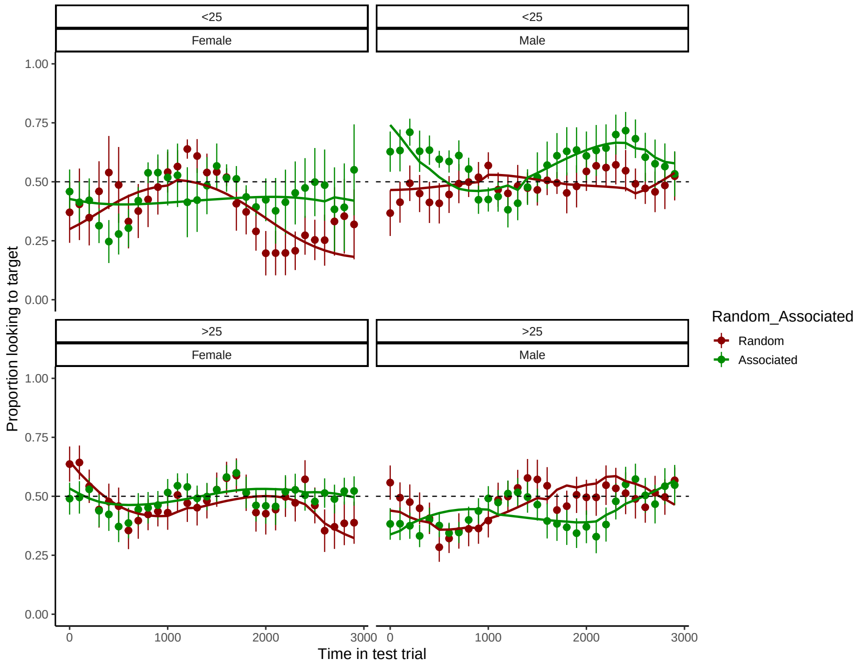

Figure 4.12: Relation between children's looking to the target on trials split for females (left) and males (right) following associated (red) and random (green) probes with model predictions. The data were split into <25th percentile (top) and >25th percentile (bottom).

4.3.3.2 Cluster analysis on data grouped by percentiles

Cluster analyses for percentiles males with vocabularies below the 25th percentile revealed 3 clusters however, none of them were significant, between 200 and 300ms, cluster t statistic = 2.25, p = .474, between 400 and 600ms, cluster t statistic = 4.55, p = .287 and lastly, between 2500 and 2700ms, cluster t statistic = 5.71, p = .186. No clusters were revealed for males with higher vocabularies or either group of females. Thus, these data do not suggest a relation between children's vocabulary measured as a percentile score and memory for objects (see Table 4.21).

4.3.4 VWM results

The hypothesis for the VWM task was that there would be a positive association between visual working memory and vocabulary, so children with more words in their vocabulary would have higher working memory. To investigate visual working memory, the proportion of looking to the change side score was used. This score is based on trials where children begin the task looking at the display that is not changing (Aneja, 2022). Spencer et al. (2023) have found this measure to vary with load (e.g., the number of items presented in the display), and thus to be more reflective of working memory capacity. We also added shift rate (how much children shifted attention between the displays) to the models as this measure has been found to be a reliable and stable marker when evaluating visual cognitive abilities (Rose et al., 2012). In particular, shift rate has been found to explain the age-related increase in visual working memory, as children who grow older are able to sustain their attention, which results to lower shift rate. Shift rate was calculated by taking the full length of any trial and counting the number of switches participants made from one side of the screen to the other, divided by the number of seconds that participants were looking at the display, resulting in shifts per second. We analysed children's proportion looking to the target (first look was to the no-change side.) with a linear mixed-effects regression model that included Load, productive vocabulary (scaled and centred) and shift rate (centred) as fixed effects and participant ID as a random effect. There were no significant effects in that model, suggesting that task performance was unrelated to vocabulary.

Prior work by Aneja (2022) using the same task has found effects of age.

Thus, we also analysed children's proportion of looking to the change side score proportion looking to the target with a linear mixed-effects regression model that included Load, Age (scaled and centred), and shift rate (continuous, centred) as fixed effects and participant ID as a random effect. There was a significant interaction between age and shift rate $\chi^2(1) = 4.89$, $p = .03$, and marginal effects of load, and Age, $\chi^2(2) = 5.59$, $p = .06$ (Table 4.22). A comparison of this model to the one using vocabulary found that Akaike's information criterion was slightly lower in the age model (73.81) than in the vocabulary model (80.94) suggesting age provided a better fit. The link between load and age is important as the loads get harder. Children who are older and should have better working memory should be able to hold more information in memory during the task. Figure 4.13 shows the relation between age and proportion looking to the change side for the three different set sizes, using a median split to show children with lower (left panel) and higher (right panel) average shift rate. As can be seen in the figure, there was a positive relation between age and VWM performance on set size two trials for children who had a lower sift rate. In contrast, there was a negative relation between VMW performance and age at all set sizes for children who had higher average shift rates. Thus, we only had evidence of a relation between VWM and age for children who shifted looking between displays less, and only at set size two. The lacked of relation between age and proportion looking to the change side for children with high shift rates could indicate that these children lack the capacity to hold even 2 items in VWM. These children kept checking the two displays because they could not remember what was in each.

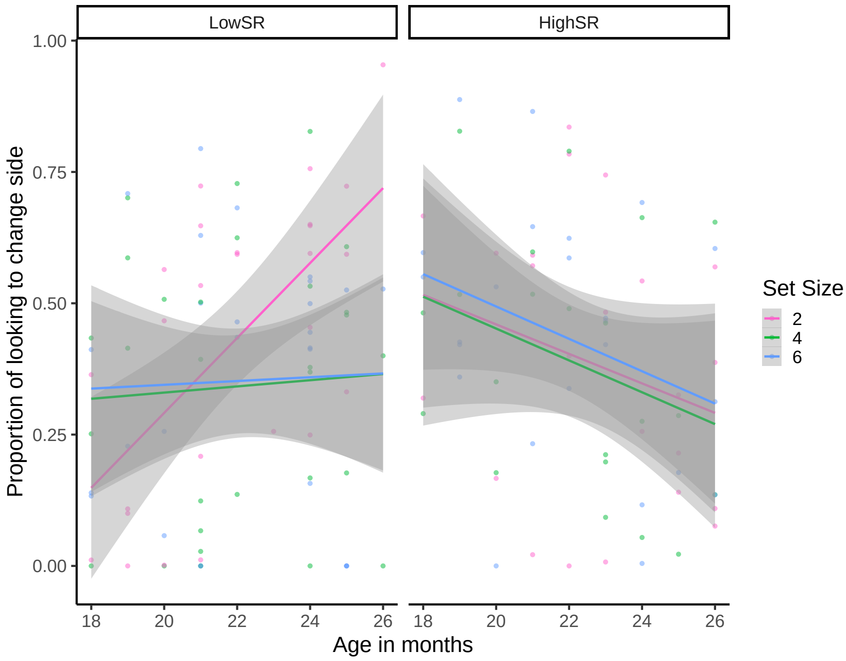

Figure 4.13: Relation between proportion of looking to change side, age (in months) and set size. The median split was used to split the data into low (left) and high (right) shift rate (SR) for visualisation purposes.

4.3.5 Summary of Individual Task Results

Overall, we found the expected relation between vocabulary and novel noun generalisation performance. There was a significant relation between both the number of nouns children knew or their total vocabulary, and attention to shape in the NNG task. Further, children who knew more nouns quickly looked to the shape matching test object after the novel name was provided in the task. These children also showed fewer looks between the test objects following the naming, event but before making a selection, compared to children who knew fewer nouns. These findings all corresponded to those presented in Chapter 2. However, contrary to the findings in the prior chapter, there was some indication that children looked more to the material matching test object before the naming event on trials on which they eventually selected the material-match. But this was on a relatively small number of trails.

We did not find the expected relation between vocabulary and our other measures of memory. There was no relation between vocabulary and retention performance. However, while children in general showed no evidence of retaining the novel names, those who completed more retention trials evidenced more retention. In the object memory task, while we did find an interaction between vocabulary, gender and looking to the target following primes associated with that target, the fact that looking to the target hovered around 50%, dampened any evidence of a relation between object memory and vocabulary. In this case the findings might suffer from the fact that animacy biases appeared to have played a significant role in children's performance, causing differences between versions of our task and the need to drop a number of trials. Finally, we did not see a significant relation between working memory performance and vocabulary. A model using age instead of vocabulary did find that for children who shifted less, there was a positive relation between age and looking to the change side on trials with 2 stimuli. Given the strong correlation between age and vocabulary in our data (R=.37, p <.001), it was surprising that vocabulary did not have a similar relation to VWM performance as age.

4.3.6 Relations between tasks

Although the results from the three memory tasks were not strong, we pursued the exploratory analyses examining links between memory and attention in the novel noun generalisation tasks. First, we examined whether higher attention to shape in the NNG would be related to higher retention of the novel name-object links presented in the task. This was based on the idea that the shape bias is associated with higher vocabulary and that retention of words should be higher in children with higher vocabularies. We created a model predicting retention by the proportion shape choices and vocabulary. The model revealed no significant effects. Given the overall low retention scores and the fact that many children did not complete all the trials, this finding was not surprising. Another linear model was run predicting the proportion success in retention by proportion of shape choices, noun vocabulary (continuous, centred and scaled) and number of completed trials (centred and scaled). The only significant effect was the number of trials completed $t(31) = 2.00$, $p = .05$, thus, this finding was identical to that depicted in the right panel of Figure 4.10.

Secondly, we explored the possibility of a relation between attention to shape and VWM, based on the idea that both are improving over the course of early vocabulary development. A model predicting proportion shape choices by noun vocabulary and proportion looking to the change side, however, revealed no significant effects. This was not surprising given the lack of vocabulary effects in our VWM data. Thus, we also ran a model predicting proportion shape choices by age and mean shift rate. This model revealed no significant effects of age $t(46) = 1.20$, $p = .24$, mean shift rate, $t(46) = .73$, $p = .47$ or interaction between age and mean shift rate, $t(46) = -.56$, $p = .58$ (Table 4.23). Thus, we do not have evidence of a relation between VWM and attention to shape in the NNG task.

The possible relation between VWM and retention of the names presented in the NNG task was examined next. Figure 4.14 shows there was a correlation between VWM performance and retention, which revealed a significant positive correlation $R = .24$, $p = .02$. Children who retained more words looked more to the change side in the VWM task. To examine the predicted relation between vocabulary, VWM performance and shift rate, a model predicting retention by mean proportion looking to the change side (after a no change first look) and vocabulary was run. This model revealed a significant main effect of noun vocabulary $t(32) = 2.17$, $p = .04$ and a significant two-way interaction between proportion looking to the change side and noun vocabulary $t(32) = -2.41$, $p = .02$ (Table 4.24). Figure 4.15 shows the relation between proportion looking to the change side and retention for children with low and high vocabulary (median split). As can be seen in the right panel, while children who knew more words did not evidence a relation between VWM and retention, children who knew fewer words (left panel) evidenced a positive relation between VWM performance and retention. Thus, stronger visual working memory is related to retention of names presented ostensively in the NNG task, for children with smaller vocabularies.

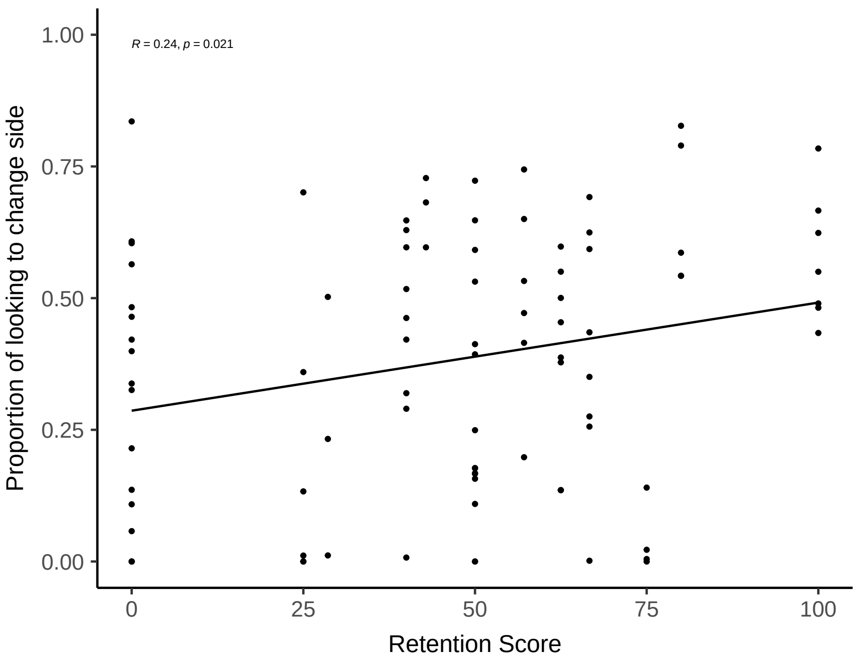

Figure 4.14: Proportion of looking to change side (VWM task) by retention score.

Third, we examined the possibility that lower visual working memory ability might explain why children with few words in their productive vocabularies looked between the test objects more before making a generalisation de-

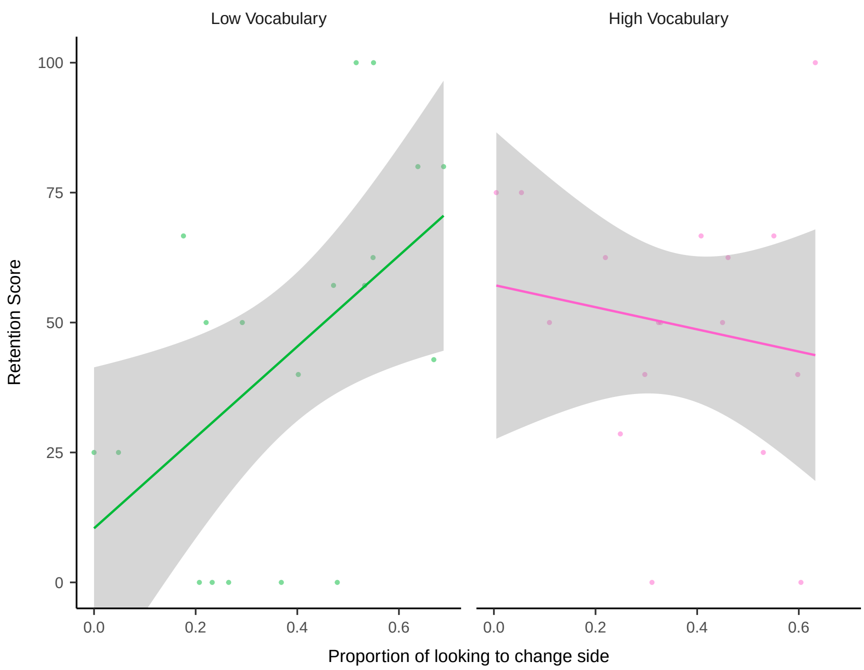

Figure 4.15: Retention score by proportion of looking to change side (VWM task). The median split was used to split the data into low (left) and high (right) vocabulary groups for visualisation purposes. Shaded regions indicate 1.5 standard deviations of the mean for each vocabulary group.

cision. A model predicting transitions in the NNG task by productive noun vocabulary (continuous), proportion looking to the change side and shift rate was run. Model simplification removed vocabulary (AIC 352.2) leaving a final model predicting transitions by proportion looking to the change side when they started on the no change side and shift rate (AIC 350.77). There was a main effect of proportion looking to the changing side z = 2.34, p = .02, and shift rate z = 2.28, p = .02 but also a two-way interaction between proportion looking to the changing side and shift rate, z = -1.94, p = .05 (Table 4.25). Figure 4.16 shows the relation between the mean number of transitions children made in the NNG task between the naming event and their selection and proportion looking to the change side in the VWM task, for children with low and high shift rates. As can be seen, this showed that the number of transitions children made increased with looking to the change side for both children with lower and higher shift rates, but that that this relation seemed to be stronger for children who made fewer shifts in the VWM task. Given that lower shift rate is indicative of better memory for the items presented in a display (Spencer et al., 2023), and that higher proportion looking to the change side is indicative of better working memory (Spencer et al., 2023) these data suggested that better performance on the VWM task is related to more transitions in the NNG task, contrary to our predictions.

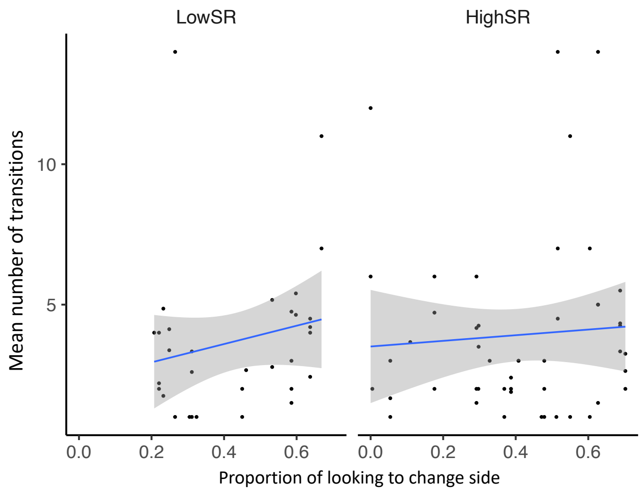

Figure 4.16: Mean proportion of looking to change side (VWM task) by mean shift rate. Solid line represents best fit linear regression.

Finally, to investigate whether stronger working memory was related to faster responding in the NNG task we used the reaction time score from the NNG task (Figure 4.17). A model predicting mean reaction time, by mean proportion looking to the change side and mean shift rate, revealed no significant effects, however. This suggested reaction time in our NNG task and visual working memory was not related in our data (Table 4.26).

To examine the expected positive, based on the literature, relation between children's memory for objects and attention to shape, we created a difference score by subtracting the proportion looking to the target on random trials

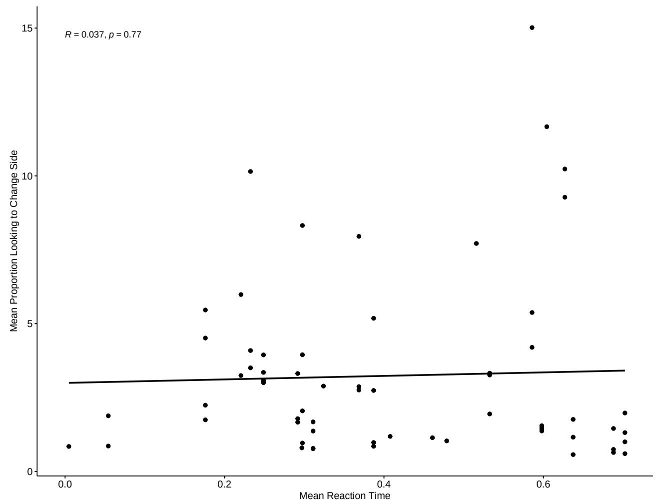

Figure 4.17: Proportion of looking to change side (VWM task) by mean reaction time (NNG task). Solid line represents best fit linear regression.

from proportion looking to the target on associated trials. A linear model predicting the proportion of shape choices by vocabulary and object memory difference revealed a significant main effect of vocabulary, as in the model of the NNG data above, $t(31) = 3.74$, $p <.001$, and a marginal main effect of difference score $t(31) = 1.99$, $p = .06$ (Table 4.27). Further, model comparison showed that a model without the difference score was better (-34.53 v -23.58). Thus, these data did not suggest a relation between object memory and the shape bias, contrary to Collisson et al. (2015). We also did not find a relation between children's object memory and retention ($R = .13$, $p = .52$). This finding was not surprising as for both retention and VPA task our data did not have a lot of power.

Lastly, to investigate if there is a relation between object memory and VWM we created a model predicting object memory difference score by productive vocabulary and mean proportion looking to the changing side. We found no significant main effect of productive vocabulary, $z = 1.22$, $p = .23$, or mean proportion looking to the changing side, $z = .34$, $p = .73$ (Table 4.28). However, there was an interaction between object memory difference score,

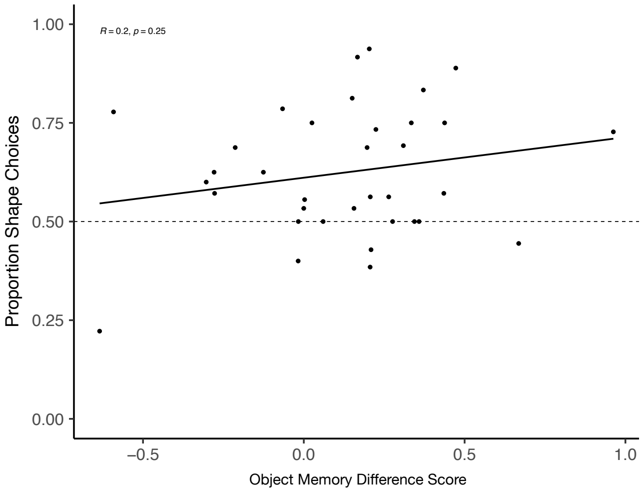

Figure 4.18: Proportion shape choice (NNG task) by object memory difference score (VPA task). Solid line represents best fit linear regression.

productive vocabulary and mean proportion looking to the changing side, z = -1.96, p = .06. Figure 4.18 shows the difference between performance on associated and random prime trials in the object memory task and children's looking to the changing side in the VWM task, for children with low and high productive vocabulary scores. As can be seen in Figure 4.19, the high vocabulary group exhibited a negative relation between object memory difference score and the mean proportion of time looking at the changing side of the VWM task. In contrast, the relation was relatively steady for the low vocabulary group. Given that positive object memory difference scores would reflect more difference between performance with associated probes relative to random, these data suggested object memory goes down with increasing VWM, at least for children who knew more words. This was an unexpected finding, however, given that the VPA data might not be particularly robust, caution is needed in interpreting these results.

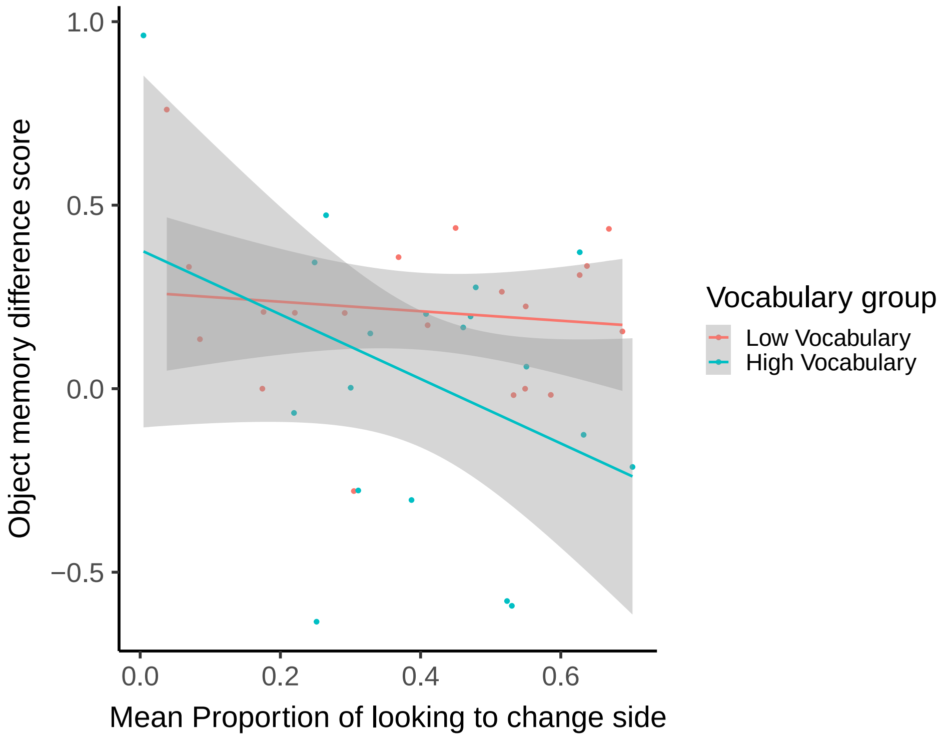

Figure 4.19: Object memory difference score (VPA task) by proportion of looking to change side (VWM task). The median split was used to split the data for the low (red) and high (blue) vocabulary groups for visualisation purposes. Shaded regions indicate 1.5 standard deviations of the mean for each vocabulary group.

4.4 Discussion

The current project expands on the idea that word learning is a fundamental building block of language acquisition and is influenced by multiple memory timescales. Specifically, it sought to understand possible relations between children's attention to object features when learning new nouns and memory abilities at multiple timescales. In addition to examining children's attention to shape in a novel noun generalisation task, it investigated children's short-term visual working memory and longer-term memories for object and word-object pairings. Productive vocabulary data was also collected. We collected data from 68 participants between 18 and 26 months of age in a within subjects' design that included a NNG task with retention trials as well as a visual paired associates task, to measure object memory, and a VWM-PL task. We looked at performance in each task in relation to vocabulary, and then performed exploratory analyses to examine relations between performance in the tasks.

4.4.1 Children's Recognition of Object Shape: Early Processing and Vocabulary Development

The words and language that we listen to around us play a role in how we move our eye gaze as we shift our attention to the objects and people mentioned. And as objects in the world are named, infants and children learn which words go with which things in the world. Analysis of the NNG task has replicated previous studies and enhanced evidence that words and children's attention are closely linked. For the NNG task, we hypothesised that there would be a positive relation between the number of nouns in the vocabulary and attention to shape during novel noun generalisation. We found that children's shape bias and productive noun vocabulary were indeed positively related. In particular, children with more nouns in their vocabulary picked more shape-matching test objects when asked to extend a novel name from an ostensively named exemplar. These findings are supported by previous research that also demonstrated this link (Bakopoulou et al., 2023; Samuelson & Smith, 1999; Smith et al., 2002). These findings are also in line with those of Lorenz and Kucker (2021, April), who also found that children with more vocabulary performed better in the NNG task.

The current study is the first to use an NNG task with an eye tracker in order to understand more precisely the relation between naming and attention to shape. Based on our prior work (Bakopoulou et al., 2023, Chapter 2), we hypothesised that children who knew many nouns would look equally at the two test objects before the naming event and then immediately look towards the shape-match test object afterwards. However, we hypothesised that children who knew fewer nouns would also look equally at the two test objects prior to the naming event, but that these children would not look directly at the shape-match test object after naming. Our investigation of children's visual exploration revealed that they looked more to the shape matching test object before the naming event, on trials when they would eventually select that object. This differed from what we had predicted, based on the findings of Chapter 2. In that chapter children looked equally to the two test objects prior to the naming event. We will return to the comparison of the data from the two chapters in the General Discussion.

The difference between the two studies in children's looking responses before the naming event was not evident in their manual exploration of the objects during the familiarisation. Here, both data sets revealed that children explored the two objects more than the exemplar, but equally. This suggests that by this measure at least, they had no particular preference for one test object over the other. An interesting question for future work would be how possible preferential attention to one stimulus before the naming event measured by looking v manual exploration are related. These phases of the task differed in that during the manual exploration phase of the experiment, children had all three objects close at hand to explore at will. In contrast, our looking measure of preference before the naming event came from the period in time between when the experimenter had retrieved all the objects (after the child had been allowed to explore them) and was then presenting them for naming (but had not yet named them). Thus, it is possible that this difference—one period being more like free play, and the other clearly moving towards a structured presentation and question—is enough to cue (some) children toward a different response to the stimuli. Examining these differences, via manipulations to the structure of the task, might be another fruitful avenue for future research.

We also examined the possibility that children engaged in a deliberative, less automatic, comparison process prior to making a generalisation decision by quantifying how much children looked back and forth between the objects after the naming event, but before making a generalisation decision. Based on the data reported in Chapter 2, we predicted that children with lower noun vocabulary would transition between objects more before choosing an object, when compared to children with a greater noun vocabulary. Indeed, we found that following the naming event, children's productive noun vocabulary influenced the transitions such that children who knew fewer nouns transitioned more, replicating our prior findings. These data then suggested that early in vocabulary development, it is not automatic to link the naming event to the shape-matching test object, whereas later it becomes automatic, presumably as more nouns are learned (c.f., Smith, 2001).

We also predicted that reaction time to make a generalisation decision would be faster for children with more nouns in their productive vocabulary. In examining the relation between reaction time and vocabulary size, the results indicated a slight decrease in reaction time as vocabulary increased, but this effect was not significant. Thus, while the reaction time data from this chapter are in line with the findings from Chapter 2, the effect was not significant.

4.4.2 Retention of Newly Learned Word-Referent Mappings

We predicted that children with more nouns in their vocabulary would retain more of the new word-object mappings presented in the NNG task than children with less noun vocabulary. However, our research demonstrated no significant word retention overall, and that infants with larger productive noun vocabularies did not appear to retain more word-object mappings. It is important to note that, our sample might have lacked power as we had very few infants who completed all six retention trials. However, we did find that retention performance was related to the number of retention trials attempted. Thus, there is the possibility our findings would have aligned with those of Lorenz and Kucker (2021, April) had more of the children in our sample completed more of the trials.

Lorenz and Kucker's (2021, April) study is the only other research, to our knowledge to have looked at retention in the NNG task. More research has looked at retention following referent selection (sometimes called disambiguation or "fast mapping"). For example, both Bion et al. (2013), and Horst and Samuelson (2008) found 24-month-old children failed to retain new mappings created in a referent selection task after a short delay. However, it is important to note that these other studies that have failed to find retention are not ostensive definition tasks such as the NNG, in which the exemplar is held up and directly named for the child. Indeed, studies suggest that children as young as 12 months retain words in such instances (Woodward, 1998). Further, even in the case of referent selection tasks, like that used by Horst and Samuelson (2008) and Bion et al. (2013), studies suggest that prior familiarisation with the stimuli, similar to the familiarisation period we included before naming the object, does lead to retention in 24-month-old children (Kucker & Samuelson, 2012). It is possible that the familiarisation period used here was not long enough. However, we favour the idea that the goals of the task might have been different here. That is, rather than creating an explicit link between an object and name in order to retrieve the correct object out of an array, as in the referent selection task, in the NNG task children might be more focused on what objects go together. Thus, the children focused on ensuring they used the word as a tool to decide which object could also be called by the same name, creating and encoding the new word-object pairing.

4.4.3 Memory for Visual Objects and Word Learning

The analysis of data from our visual paired associates object memory task was hampered by having to drop trials due to differences in children's attention to animate v inanimate objects. However, we did find some indication of a relation between object memory, vocabulary and gender. There was a general tendency to look at the target in trials following an associated probe, suggesting that children could remember the pairs of familiar objects. But this tendency appeared more strongly for children with lower vocabularies or who had a lower vocabulary percentile score. Thus, the findings went against our proposal that there would be a positive relation between object memory and vocabulary, and prior work with similar tasks (Collisson et al., 2015; Vlach & DeBrock, 2017). Our results did fit the findings reported in Chapter 3 with respect to overall vocabulary score. However, in that prior study we did find that children in a higher percentile group performed better in the task.

One possible cause of the unexpected finding that object memory is related to lower vocabulary is that the children with larger vocabularies were seeking out the most interesting and novel object – the distractor – rather than the familiar object that had previously been paired with the probe. That is, children with larger vocabularies might have identified the target, but as it had been seen more recently during the memory array, they had then looked away. Thus, they might have experienced a habituation effect (Poli et al., 2024; Lloyd-Fox et al., 2019; Shinskey & Munakata, 2010). Young infants with lower vocabulary develop a strong representation for familiar objects when they have seen them multiple times as they focus on visual stimulus to create strong representation of them (Shinskey & Munakata, 2010). On the other hand, older infants with larger vocabulary show a novelty preference, which maybe be due to them having a stronger representation of the familiar object. Thus, their performance is influenced maybe how strong the representations are for the object they know, which seems to be influenced by developmental transitions (Shinskey & Munakata, 2010). Therefore, the performance in visual preference tasks is influenced by the strength of the children's object representations.

It is also worth noting that there are methodological differences between our task and the Vlach and DeBrock (2017) task that revealed larger vocabulary sizes correlate with better word learning, and the Collisson et al.'s (2015) task with older children. The use of eye tracking technology in our study allowed prolonged monitoring of visual attention, possibly aiding performance among younger participants. Eye tracking provides a less demanding measurement method, which was especially beneficial for young children. In contrast with Vlach and DeBrock (2017) who relied on single discrete responses, which might limit observations of younger children's capabilities. There were also differences in the results of by Collisson et al. (2015), who found a positive correlation between vocabulary size and performance in a similar task but used different stimuli. However, their target group were participants between 4-5 years old as they were able to follow verbal instructions about pairing symbols with pictures as well as provide more explicit responses. These differences may be usefully examined in future work.

4.4.4 Working Memory and Word Learning

Results of the VWM task indicated that the higher loads were hard for children in this study, as they only seemed to be able to hold up to two items at most in visual working memory. This contrasts with prior research that has found that from 10 to 13 months, infants demonstrate VWM capacity for arrays containing two and three items memory load (Ross-Sheehy et al., 2003). For VWM, we predicted that there would be a positive association between VWM and vocabulary, following the idea that VWM does support early vocabulary development. We did find that children's age was significantly related to their performance. On trials with two items, infants' performance improved significantly as they got older. This aligns with other studies (Aneja, 2022; Spencer et al., 2023) that assessed VWM and found that up to the age of three, children's VWM capacity is around two or three items (Simmering, 2012). Age is usually strongly connected to vocabulary, so we might assume that similar differences in VWM performance occurred with increasing vocabulary knowledge. However, analysis of VWM performance by vocabulary was not significant.

Notably, the analysis of VWM also included shift rate, representing the number of times a participant transitioned their gaze between the two arrays, as a predictor. The use of the shift rate in the analysis was motivated by Spencer et al. (2023) and Rose et al. (2012) who both showed that visual processing speed in infancy is predictive of longer-term cognitive outcomes. The interaction between shift rate and age revealed a significant relation with VWM. In our data, infants with low shift rates showed a greater proportion of looks towards the changing array that was positively correlated with age. For infants with a high shift rate, the opposite trend emerged, with the proportion of looks to the changing array exhibiting a negative correlation with age, suggesting decreasing VWM in older children.

This contradictory pattern suggested that the shift rate could be interpreted as an additional metric for VWM. High shift rates might reflect limitations in VWM capacity, necessitating multiple array comparisons for change detection and memory consolidation. To that extent shift rate had been used as an alternative metric of memory, this interpretation gained traction in younger infants, whose typically weaker VWM benefits from increased visual sampling. However, in older infants expected to possess more developed VWM, fewer shifts suffice for change detection, implying that high shift rates may signify VWM difficulties. Alternatively, rapid gaze shifts could point towards attentional challenges, such as limited fixation durations, particularly in older infants. This aligns with prior research that highlighted that visual processing metrics such as the shift rate serve as reliable indicators of both age-related and individual differences in visual cognition and VWM (Colombo, Mitchell, & Horowitz, 1988; Fry & Hale, 1996). Thus, our findings with respect to VWM performance and age are broadly in line with prior reports in the literature.

4.4.5 Relations between Word-Learning Processes, Retention and Visual Memory timescale

One interesting possibility of how performance in our measures could be related was that the children's attention to shape would be related to retention performance. However, this was not supported. This is likely because very few children completed more than half of the retention trials. We also proposed that higher vocabulary would be the link to both better attention to shape and better object memory. Our results showed that there was no relation between novel noun generalisation and object memory. This contradicts the findings of Collisson et al. (2015) who found a link between a visual paired-associate learning task and vocabulary development in pre-schoolers. Specifically, the performance of typical learners steadily improved in their VPA task and these children had more correct responses compared to a group of children with SLI, whose performance stayed at chance. Collisson et al. (2015) concluded that the ability to remember novel pairings of visual stimuli may be one difficulty faced by children with slow vocabulary development, in this case children with SLI. However, these data come from children who are 1 to 2 years older than those in the present sample. It is also the case that the data presented here on object memory should be taken with caution, given the large number of trials that had to be removed from analysis.

Further analysis revealed no relation between paired-object memory and infants' tendency to generalise novel names by shape. This finding contradicts previous research that showed object memory performance was a strong predictor of both word-learning processes and longer-term word learning. However, the limitations of the object memory task used here might have weakened the power of these comparisons, leading to the null results observed. Therefore, further analysis of the relation between word-learning biases and object memory using an alternative task to VPA might be warranted.

Alternatively, the ability to remember and pair objects together, which was specifically measured in these tasks, might not be directly correlated with word-learning strategies. While it was previously assumed that this ability to learn simple pairings of visual objects would likely reflect the more complex multi-modal skills required for word-object association and thus be relevant to word-learning processes (similar to Vlach & DeBrock, 2017), other aspects of object memory might be more important. Research has established a connection between the extent of shape bias in participants and their memory for object features (Perry et al., 2016; Vlach, 2016). Consequently, investigating the relation between object-feature memory and the word-learning strategies observed in NNG could provide a more insightful avenue for further research. Moreover, a more comprehensive measure of object recognition, such as the object caricature tasks employed by Jones and Smith (2005), might reveal stronger connections to word-learning processes. Research on memory also indicates that as time passes, there is increased flexibility, potentially illuminating how novel words are retained and generalised (Wojcik, 2017). Wojcik (2017) supported the idea that memory and particularly consolidation could be context dependent. This perspective suggests that the context which memories are acquired influence their ability to be retrieved. In relation to our study this could be related to why we did not find associations between retention, novel noun generalisation and paired object memory as we did not have any specific context cues which could have supported the memory encoding and retrieval processes.

We also expected VWM to be related to more attention to shape in the NNG task. However, analysis revealed no significant association between VWM capacity and attention to shape, suggesting that the little variation in shape bias was not related to VWM. In addition, we found retention to be significantly related to VWM such that greater VWM performance was related to better word retention. Our study further revealed a significant interaction between VWM ability, age and vocabulary in predicting word retention. Younger children and those with smaller vocabularies exhibited better word retention when they also possessed stronger VWM skills. In contrast, older children and those with larger vocabularies demonstrated minimal differences in word retention across varying VWM abilities. This could be related to the idea that older infants with larger vocabularies likely possess enhanced long-term memory (LTM) capabilities. As a result, they can retain word-object pairings irrespective of VWM strength disparities. Conversely, younger children or those with smaller vocabularies may have weaker LTM mechanisms for word-object mappings (Schurgin, 2018) and thus rely more heavily on the strength of their VWM to process and encode these mappings. In essence, these children require stronger VWM abilities to effectively encode word-object associations in LTM. In this way, then, these results suggested a connection between VWM abilities and the emergence of effective word-learning strategies. Hence, we may infer that VWM might also play a role in successful word acquisition and vocabulary expansion. In this way, then, this finding aligns with previous research that indicated that reduced VWM capacity is associated with language acquisition challenges (Bavin, Wilson, Maruff, & Sleeman, 2005; Petruccelli et al., 2012) and research that has shown that children with language delays tend to have weaker working memories (Smolak et al., 2020; Vissers et al., 2015; Blom & Boerma, 2020).

We also examined the relation between the proportion of looking to the change side and the shift rate in predicting looking transitions during the period of time between the naming event and children's selectins in the NNG task. We found that children with a higher proportion of looking to the changing side, indicating better VWM, exhibited higher shift rates and more transitions in the NNG task, while those with a lower proportion showed decreasing transitions. This meant that children with strong working memory needed to transition more between objects in the NNG task. Fernald and Marchman (2012) also showed that memory performance is supported by attentional shifts even in school life. This indicates that VWM provides important insight about children early childhood development.

Lastly, we also investigated whether VWM would also be related to faster responses in the NNG task. Although we hypothesised, based on previous research linking VWM and specifically shift rate to faster responses in related tasks (e.g., Buss et al., 2018; Simmering, 2012; Delgado Reyes et al., 2020; Deldar, Gevers-Montoro, Khatibi, & Ghazi-Saidi, 2020), that VWM would be associated with quicker responses in the NNG task, our findings did not support this. This discrepancy suggests that the connection between VWM and task performance might be more task-specific or context-dependent than previously thought, warranting further investigation.

Broadly speaking, our research adds to the growing body of literature exploring the relation between memory and language development. Pickering et al. (2023) conducted a comprehensive review of studies and identified a significant link between the ability to recall pairs of visual stimuli and vocabulary growth, which aligns with our findings as younger children with smaller vocabularies were better at remembering pairs of objects; however, it isn't in line with our data from older children who had larger vocabularies and did not remember pairs of objects successfully. Pickering et al. (2023) highlighted that individuals with stronger visual memory, particularly in tasks involving the recall of visual pairs, tend to have larger vocabularies, emphasising the critical role of visual memory in early language acquisition. Their research suggests that improving visual memory could play a pivotal role in fostering vocabulary development, especially in early educational settings. By enhancing children's overall memory, educators could support better word recognition and retention, ultimately promoting language development. This underscores the value of incorporating visual learning techniques in early childhood education to support language and cognitive development. Overall, our findings are consistent with an expanding body of research that connects memory with language learning (Reynolds, 2015; Vlach & Sandhofer, 2012).

4.4.6 Limitations and Future Directions

There are some limitations and modifications to consider. Even though it was very useful to collect all the data in two sessions, it also had a possible downside in that participants' performance might have not been stable. This is attributed to the significant number of incomplete trials, indicating that the youngsters may have found it overwhelming to complete all the trials within two sessions. This may indicate that a better design would have spread the multiple tasks over more than two sessions. Further, a future study, that used multiple sessions at multiple ages in a more longitudinal design child could provide richer data about the relation between the tasks and the children's vocabulary. The observation of these systems over time could enhance the understanding of the different pathways and multiple timescales at which vocabulary develops. This could also help guide early assessment of language delay so that individuals who might otherwise go on to experience word-learning difficulties could be identified before they do so. Subsequent research should continue to examine how language, memory and other cognitive systems interact and contribute to word learning.

In addition, we did not consider socio-economic status (SES) extensively and how it might influence the performance on the tasks. We tried very hard to collect data from children from with lower SES background which has been related to slower word learning (Schwab & Lew-Williams, 2016). While we were able to recruit some participants from lower SES backgrounds, the sample size was too limited to draw strong conclusions. Expanding our focus onto a wider demographic might offer a sample that includes more on children from different backgrounds and provide further understanding of the relation between children's performance on these tasks and their later language abilities.

Also, having more participants might increase the potency of our results and match the study by Lorenz and Kucker (2021, April) more closely as they collected data from 330 children. Assessing the retention of word-object pairings could be completed at a different stage that would allow further extension of learning processes. This could lead to the exploration of a wider relation between word-learning processes and retention that enables children to have more concrete retention as known objects were also used.

Another limitation encountered was the animacy effect which was identified in the VPA task which measured object memory. Children looked more at an animate object (e.g. a dog), compared with an inanimate object (e.g. a chair) regardless of whether it was the target or the distractor. Previous literature found that infants' attention was biased to attend to animacy. Therefore, considering the use of animacy in the task is vital (DeLoache et al., 2011; Simion et al., 2008). This led us to remove any trials that included stimuli that were mixed in animacy. This limited the conclusions we could draw from our object memory task. In the same task another issue was that there was also a lack of guidance regarding the probe, as there were no verbal instruction on what the children should do. Having explicit instruction and presenting objects in a more tangible way might prove beneficial to provide more support for the children on what to do.

4.4.7 Conclusions

This study examined the relation between early word learning and memory abilities at multiple timescales. It particularly focused on visual attention to shape similarities in novel noun generalisation tasks, vocabulary and memory at both short-term (VWM) and longer-term timescales (object memory and retention for new word-object mappings). Our findings demonstrate a significant correlation between children's ability to generalise nouns by shape and their vocabulary and that children who know more nouns quickly attend to shape following a naming event. Furthermore, significant relationships were identified between vocabulary, retention and visual working memory as well as between children's visual exploration of objects and reaction time. There was also a link between children's proportion shape choice, object memory and visual working memory. We also found that vocabulary positively influenced children's abilities to generalise new words but it did not influence object memory and visual working memory in the same way.

In conclusion, this study provides evidence for the interconnected development of shape bias, vocabulary, visual attention, and memory in young children. The results indicate that vocabulary plays a role in children's attention to objects and object memory, while age appears to be a better predictor for visual working memory. Although vocabulary and age are highly correlated, our data suggest that other factors may mediate this relation, indicating that different variables might have more influence and be better predictors for memory across different timescales.

4.5 Significance Tables

Table 4.6: Regression results for proportion shape choice by noun productive vocabulary

Variable	Estimate	Std. Error	t value	p-value
(Intercept)	0.13	0.02	5.95	$< .001^{***}$
OCDI_2_10_sc	0.06	0.02	2.80	$< .01^{**}$

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.7: Regression results for proportion shape choice by total productive vocabulary

Variable	Estimate	Std. Error	t value	p-value
(Intercept)	0.12	0.02	5.97	$< .001^{***}$
OCDI_2_10_sc	0.06	0.02	2.85	$< .01^{**}$

Note. Blank indicates *p<.05. **p<.01. ***p<.001.

Table 4.8: Regression results for proportion shape choice by age

Variable	Estimate	Std. Error	t value	p-value
(Intercept)	0.12	0.02	5.74	$< .001^{***}$
Age_sc	0.04	0.02	1.88	$.06^{\cdot}$

Note. Blank indicates *p<.05. **p<.01. ***p<.001.

Table 4.9: Regression results for proportion shape choice comparing hand coded and eye tracked data by productive noun vocabulary

Variable	Estimate	Std. Error	t value	p-value
Intercept	41020.71	6851.86	5.99	$< .001^{***}$
OCDI_2_10	-134.32	68.11	-1.97	$.05^{*}$
Categoryeyetracking	4101.62	8980.15	0.46	0.65
OCDI_2_10:Categoryeyetracking	11.53	83.72	0.14	0.89

Note. Blank indicates *p<.05. **p<.01. ***p<.001.

Table 4.10: Regression results for looking time course before the naming event

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	0.07	0.09	0.74	.46
Final_Selection_s	0.47	0.18	2.64	$< .01^{**}$
OCDI_2_10_sc	-0.059	0.09	-0.660	.51
Final_Selection_s:OCDI_2_10_sc	0.12	0.18	0.69	.49

Note. Blank indicates *p<.05. **p<.01. ***p<.001.

Table 4.11: Regression results for looking time course after the naming event

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	-0.07	0.09	-0.75	.45
Final_Selection_s	0.99	0.17	5.73	$< .001^{***}$
OCDI_2_10_sc	0.00	0.08	0.02	.99
Final_Selection_s:OCDI_2_10_sc	0.17	0.17	1.02	.31

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.12: Regression results predicting proportion shape responding by vocabulary with random intercepts for trials ending in shape selections

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	0.46	0.11	4.05	$< .001^{***}$
OCDI_2_10_sc	0.09	0.11	0.78	.44

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.13: Regression results predicting proportion shape responding by vocabulary with random intercepts for trials ending in material selections

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	-0.58	0.15	-3.99	$< .001^{***}$
OCDI_2_10_sc	-0.08936	0.14454	-0.618	0.536

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.14: Regression results predicting children's final selection by proportion looking to the shape-match test object before the naming event

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	0.23	0.15	1.49	0.14
Prop	0.65	0.24	2.72	$.01^{**}$
OCDI_2_10_sc	0.21	0.15	1.42	0.16
Prop:OCDI_2_10_sc	0.23	0.24	0.98	0.33

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.15: Regression results predicting children's final selection by proportion looking to the shape-match test object after the naming event

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	-0.79	0.15	-5.10	$<.001^{***}$
Prop	2.64	0.27	9.77	$<.001^{***}$
OCDI_2_10_sc	0.34	0.15	2.27	$.02^{*}$
Prop:OCDI_2_10_sc	-0.16	0.27	-0.60	0.55

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.16: Regression results for transitions data of looking to the test objects by productive noun vocabulary

Variable	Estimate	Std. Error	z value value	p-value
(Intercept)	1.29	0.10	13.30	$<.001^{***}$
OCDI_2_10_sc	-0.23	0.09	-2.46	$.01^{**}$

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.17: Regression results for reaction time by productive noun vocabulary

Variable	Estimate	Std. Error	df	t-value	*p*-value
(Intercept)	3.93	0.56	105.00	6.98	$<.001^{***}$
OCDI_2_10_sc	-0.72	0.66	20.83	-1.09	0.29

Note. Blank indicates $*p$ ¡ .05, $**p$ ¡ .01, $***p$ ¡ .001.

Table 4.18: Chi-Square Test results for children's familiarisation data

Variable	Chi-square	Degrees of Freedom (Df)	p-value
(Intercept)	491.72	1	$<.001^{***}$
object	63.10	2	$<.001^{***}$

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.19: z statistics for model predicting proportion of shape choices by vocabulary and proportion familiarisation time spent touching the exemplar, shape-matching or material-matching test object.

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	0.35	1.39	0.25	.80
OCDI_2_10	0.01	0.01	0.57	.57
Shape_prop	-0.68	2.07	-0.33	.74
Material_prop	-0.80	2.44	-0.33	.74
Exemplar_prop	1.41	2.81	0.501	.62
OCDI_2_10:Shape_prop	0.00	0.02	0.22	.82
OCDI_2_10:Material_prop	0.00	0.02	0.2	.84
OCDI_2_10:Exemplar_prop	-0.02	0.02	-0.82	.41

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.20: Regression results for object memory by vocabulary and gender

Variable	Estimate	Std. Error	z value value	p-value
(Intercept)	-0.30	0.11	-2.69	< .01**
ot1	-0.66	0.44	-1.48	.14
ot2	-0.94	0.46	-2.06	.04*
ot3	-0.84	0.38	-2.21	.03*
Random_Associated	0.24	0.05	5.01	< .001***
OCDI_S_sc	0.09	0.11	0.81	.42
Gender_sc	-0.36	0.22	-1.63	.10
ot1:Random_Associated	0.83	0.27	3.07	< .01**
ot2:Random_Associated	0.95	0.27	3.51	< .001***
ot3:Random_Associated	0.52	0.27	1.94	.05
ot1:OCDI_S_sc	-0.23	0.44	-0.52	.61
ot2:OCDI_S_sc	1.10	0.45	2.44	< .01*
ot3:OCDI_S_sc	0.21	0.38	0.57	.57
Random_Associated:OCDI_S_sc	-0.16	0.05	-3.48	< .001***
ot1:Gender_sc	-2.92	0.89	-3.28	< .01**
ot2:Gender_sc	-1.27	0.91	-1.39	.16
ot3:Gender_sc	-0.84	0.76	-1.10	.27
Random_Associated:Gender_sc	0.28	0.09	2.97	< .01**
OCDI_S_sc:Gender_sc	0.04	0.22	0.17	.87
ot1:Random_Associated:OCDI_S_sc	0.53	0.27	1.99	.05·
ot2:Random_Associated:OCDI_S_sc	-0.89	0.27	-3.36	< .001***
ot3:Random_Associated:OCDI_S_sc	0.38	0.26	1.44	.15
ot1:Random_Associated:Gender_sc	1.88	0.54	3.47	< .001***
ot2:Random_Associated:Gender_sc	0.70	0.54	1.29	.20
ot3:Random_Associated:Gender_sc	0.22	0.53	0.42	.68
ot1:OCDI_S_sc:Gender_sc	0.19	0.87	0.22	.83
ot2:OCDI_S_sc:Gender_sc	1.50	0.90	1.66	.10
ot3:OCDI_S_sc:Gender_sc	1.29	0.75	1.72	.09
Random_Associated:OCDI_S_sc:Gender_sc	0.23	0.09	2.47	< .01**
ot1:Random_Associated:OCDI_S_sc:Gender_sc	-0.21	0.54	-0.40	.69
ot2:Random_Associated:OCDI_S_sc:Gender_sc	-0.16	0.53	-0.31	.76
ot3:Random_Associated:OCDI_S_sc:Gender_sc	-2.29	0.52	-4.36	< .001***

Note. Fixed effects are displayed including the Time term represented as ot1 (linear), ot2 (quadratic) and ot3 (cubic) Blank indicates *p<.05. **p<.01. ***p<.001.

Table 4.21: Regression results for object memory by percentiles and gender

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	-0.59	0.20	-2.94	< .01**
ot1	-2.49	0.80	-3.11	< .01**
ot2	-2.71	0.85	-3.18	< .01**
ot3	0.43	0.73	0.59	.55
Random_AssociatedAssociated	0.55	0.09	6.36	< .001***
Percentile_S	0.01	0.00	1.80	.07
Gender_sc	-0.39	0.40	-0.99	.32
ot1:Random_AssociatedAssociated	2.22	0.50	4.40	< .001***
ot2:Random_AssociatedAssociated	2.35	0.50	4.67	< .001***
ot3:Random_AssociatedAssociated	-1.60	0.49	-3.26	< .01**
ot1:Percentile_S	0.04	0.01	2.97	< .01**
ot2:Percentile_S	0.04	0.01	2.56	.01*
ot3:Percentile_S	-0.02	0.01	-1.99	< .05*
Random_AssociatedAssociated:Percentile_S	-0.01	0.00	-4.70	< .01***
ot1:Gender_sc	-1.76	1.60	-1.10	.27
ot2:Gender_sc	-4.02	1.70	-2.37	< .02*
ot3:Gender_sc	-1.50	1.45	-1.03	.30
Random_AssociatedAssociated:Gender_sc	-0.25	0.17	-1.43	.15
Percentile_S:Gender_sc	0.00	0.01	0.02	.99
ot1:Random_AssociatedAssociated:Percentile_S	-0.03	0.01	-3.56	< .001***
ot2:Random_AssociatedAssociated:Percentile_S	-0.03	0.01	-3.41	< .001***
ot3:Random_AssociatedAssociated:Percentile_S	0.04	0.01	5.16	< .001***
ot1:Random_AssociatedAssociated:Gender_sc	1.53	1.01	1.52	.13
ot2:Random_AssociatedAssociated:Gender_sc	1.55	1.01	1.54	.12
ot3:Random_AssociatedAssociated:Gender_sc	2.24	0.98	2.29	< .02*
ot1:Percentile_S:Gender_sc	-0.03	0.03	-1.27	.20
ot2:Percentile_S:Gender_sc	0.05	0.03	2.00	< .05*
ot3:Percentile_S:Gender_sc	0.02	0.02	0.84	.40
Random_AssociatedAssociated:Percentile_S:Gender_sc	0.01	0.00	3.85	< .001***
ot1:Random_AssociatedAssociated:Percentile_S:Gender_sc	0.02	0.02	0.96	.34
ot2:Random_AssociatedAssociated:Percentile_S:Gender_sc	-0.02	0.02	-1.11	.27
ot3:Random_AssociatedAssociated:Percentile_S:Gender_sc	-0.05	0.02	-2.91	< .01**

Note. Fixed effects are displayed including the Time term represented as ot1 (linear), ot2 (quadratic) and ot3 (cubic) Blank indicates *p<.05. **p<.01. ***p<.001.

Table 4.22: Chi-Square Test Results for visual working memory model by load, age and shift rate

Variable	Chi-square	df	p-value
(Intercept)	276.31	1	$< .001^{***}$
Load	1.21	2	.545
Age_in_months_sc	0.00	1	.10
SR_c	0.00	1	.975
Load:Age_in_months_sc	5.59	2	0.06.
Load:SR_c	1.33	2	.514
Age_in_months_sc:SR_c	4.89	1	0.03^{*}
Load:Age_in_months_sc:SR_c	2.42	2	.30

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.23: Regression results for proportion shape choice, age and mean shift rate

Variable	Estimate	Std. Error	t-value	p-value
(Intercept)	0.07	0.42	0.16	0.87
Age_in_months	0.02	0.02	1.20	0.24
SR_M	0.65	0.89	0.73	0.47
Age_in_months:SR_M	-0.02	0.04	-0.56	0.58

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.24: Regression results for retention trials and proportion looking to the change side and noun productive vocabulary

Variable	Estimate	Std. Error	t-value	p-value
(Intercept)	31.61	10.16	3.11	$< .00^{**}$
Prop_NC_M	36.09	24.16	1.50	.14
OCDI_2_10_sc	21.44	9.90	2.17	$.04^{*}$
Prop_NC_M:OCDI_2_10_sc	-53.83	22.33	-2.41	$.02^{*}$

Note. Blank indicates **p*<.05. ***p*<.01. ****p*<.001.

Table 4.25: Regression results for mean transitions by proportion of looking to change side and shift rate

Variable	Estimate	Std. Error	z value	p-value
(Intercept)	0.23	0.42	0.55	.59
Prop_NC_M	2.25	0.96	2.34	.02*
SR_M	1.50	0.66	2.28	.02*
Prop_NC_M:SR_M	-3.28	1.69	-1.94	.05$^{\cdot}$

Note. Blank indicates $^{*}p<.05$. $^{**}p<.01$. $^{***}p<.001$.

Table 4.26: Chi-squared test results predicting mean reaction time, by mean proportion looking to the change side and mean shift rate

Variable	Chi-square	df	p-value
(Intercept)	1.37	1	0.24
Prop_NC_M	0.01	1	0.92
SR_M	0.29	1	0.59
Prop_NC_M:SR_M	0.23	1	0.63

Note. Blank indicates $^{*}p<.05$. $^{**}p<.01$. $^{***}p<.001$.

Table 4.27: Regression results for proportion shape choice and object memory difference score

Variable	Estimate	Std. Error	t-value	p-value
(Intercept)	0.10	0.03	3.74	$<.001^{***}$
OCDI_2_10_sc	0.10	0.05	3.76	$<.001^{***}$
FamDiff	0.16	0.08	1.99	.06$^{\cdot}$
OCDI_2_10_sc:FamDiff	-0.02	0.079	-0.28	.78

Note. Blank indicates $^{*}p<.05$. $^{**}p<.01$. $^{***}p<.001$.

Table 4.28: Regression results for object difference score and proportion looking to the change side with productive vocabulary

Variable	Estimate	Std. Error	t value	p-value
(Intercept)	0.13	0.17	0.73	.47
OCDI_S	0.00	0.00	1.22	.23
Prop_NC_M	0.13	0.38	0.34	.73
OCDI_S:Prop_NC_M	-0.00	0.001	-1.96	.06$^{\cdot}$

Note. Blank indicates $^{*}p<.05$. $^{**}p<.01$. $^{***}p<.001$.

Chapter 5

General Discussion

The goal of this thesis is to expand understanding of the role of memory and attention in children's acquisition of words which forms a critical foundation for early development. Specifically, it aims to contribute to our understanding of the relation between children's attention to shape when learning new words, their memory abilities at multiple timescales (short-term and long-term memory), and their early vocabulary development. We focused on long-term retention of new mappings formed in a noun generalisation task, object memory, and visual working memory. As reviewed in Chapter 1, the literature highlights the roles of attention and memory in early word learning, suggesting that variations in these abilities may contribute to differences in children's vocabulary development. This idea stems from consideration of the tasks presented to the children when adding a new word to their vocabularies including processes related to visual attention and object processing, that help determine possible referents in a visual scene, attentional processes that may selectively focus attention on relevant properties of available referents, and memory processes that store representations of referents and the created word-referent mappings.

The interconnectedness of these processes for word learning is also suggested by claims in the literature that they are related. Thirty years of research has documented that children's visual attention system prioritises shape when trying to identify a new word (Landau et al., 1988; Smith et al., 2002; Samuelson, 2002). More recently, the shape bias has been suggested to be a memory bias (Vlach, 2016; Perry et al., 2016). Given that adding a new word to the vocabulary requires remembering the new word object mapping and generalising this to new instances within the named category. Thus, it is likely the attention processes involved in the early noun generalisation are linked to memory. Likewise, there are suggestions that memory—particularly object and working memory—together with attention processes are also related to early noun generalisation (Pickering et al., 2023). And, the prior studies by Vlach and DeBrock (2017) and Collisson et al. (2015) suggest a positive relation between memory and biased attention when learning nouns, with children who know more words and who are better at remembering pairs of objects, being more likely to demonstrate a shape bias. This further connects with the review findings by Pickering et al. (2023), who found that less robust visual working memory processes are associated with more frequent shifts in attention between objects, particularly in children with smaller vocabularies. Thus, the literature supports that the attention and memory systems together contribute to the addition of new words to the vocabulary at an early stage. Hence, additional research is required to examine these interactions and further clarify their roles in early language development.

To reach our goal, we conducted three studies focusing on three primary questions. The first question was how the automatic allocation of attention in the novel noun generalisation (NNG) task is related to vocabulary. Specifically, examining whether there is evidence that the naming event of the NNG task directly cues attention to shape, and if this is related to the size of the vocabulary. This also, then, touches on the issue of whether the shape bias is a learned association between naming events and relevant properties of objects or if it is more conceptually based. Following this, the second question concerned the relation between object memory and vocabulary in children aged 14–26 months. Results from the first two empirical studies confirmed a relation between vocabulary and attention to shape in the novel noun generalisation task and a relation between vocabulary and object memory in a visual paired associate task. Finally, the third question examined the relation between attention to shape, vocabulary, and children's memory at multiple timescales in detail. It also examined whether children's short- and long-term memory is related to vocabulary. In this chapter, we review the findings from the previous empirical chapters in response to the research questions. We also compare these findings to the prior results in the literature. Following this, a refined picture of the relation between attention, memory and word learning, based on the work that is discussed in this thesis, is presented before turning into the limitations.

5.1 Early Word Learning and Vocabulary Development

The first research question concerning how the automatic allocation of attention in the NNG task is related to vocabulary was addressed in Chapter 2 and Chapter 4. In Chapter 2, we examined how the number of nouns children know related to their attention to shape when learning new nouns. In this task, children between 17-31 months of age participated in a novel noun generalisation task with an embedded looking-while-listening procedure. Our results replicated previous findings, showing that attention to shape increased with the number of nouns in children's productive vocabularies. To investigate children's visual attention and exploration when learning new nouns, we incorporated a moment-by-moment looking paradigm into the NNG task. We found that children with more extensive productive vocabularies increased their attention to the shape-matching test objects after the naming event, suggesting that this event guided them, as their gaze was equally divided between the two test objects before the naming event. Our data supported the idea that the novel name cued attention to shape rather than the bias resulting from a deliberative comparison process, at least for children who produced many nouns. That said, we did find that children who knew fewer nouns did look back and forth between the stimuli before making a generalisation decision. This suggested their responses might be the product of a more deliberative process.

Our work thus contributes to the literature on shape bias by being the first to use a moment-by-moment looking paradigm, which allowed us to examine the importance of visual exploration of the objects before and after children made their choices. Furthermore, the fact that children did not focus more on the shape-matching test object, during the object familiarisation period before the naming sequence, suggests that their attentional bias was not driven by a general preference for shape-matching stimuli. Instead, the children appeared to explore the objects – both visually and manually – without any bias before the naming event. Our findings suggest that the naming event activates children's existing noun vocabulary knowledge, directing their attention to the most commonly relevant perceptual feature within their known vocabulary. In addition, the finding with regard to more visual exploration when the vocabulary is smaller, might suggest that children with less developed vocabulary need to look more to objects to refresh their memory of the choices. This might align with research suggesting that active visual exploration and object identification could enhance children's working memory representations (James et al., 2014).

We further pushed the NNG methodological approach by including an eye-tracking task (Chapter 4). We replicated the task used in Chapter 2, while tracking children's looking in the vertical 2D plane of the experimental space. Despite this adaptation, the results closely replicated the earlier findings from Chapter 2 in this thesis. We found that children's attention to shape-matching objects when generalising novel nouns is related to vocabulary development and cued by the naming event. Children's shape bias and productive noun vocabulary in word learning do indeed show a positive correlation. In particular, children with more nouns in their vocabulary selected more shape-matching test objects.

Our findings from both the second and fourth chapters, including children's looking patterns via coding and eye-tracking measures, largely replicated previous research. Both studies by Smith et al. (2002) and Samuelson and Smith (1999) found that children with a larger noun vocabulary exhibit higher shape bias performance. According to Smith's attentional learning account (Smith, 2001) this relation suggests the early vocabulary trains attention to shape. In support of this idea, Smith et al. (2002) and Samuelson (2002) demonstrated that children's shape bias could be trained, specifically by teaching 15- to 20-month-old children names for lexical categories organised by shape, and testing their NNG performance. They found that the children who were trained with shape-based categories demonstrated a shape bias.

However, one difference between the findings in Chapter 4 compared to

Chapter 2 was that some children did appear to move their gaze and attention to the object they would eventually choose as the referent of the novel name, before the naming event. One possible source of this effect, especially given the smaller number of trials that may be contributing to the effect, is that it reflected performance in later trials when children had become more accustomed to the task. That is, during the initial trials of the novel noun generalisation task children might be figuring out what the task was and what they were supposed to be doing. While we did always start the task with a series of warm-up trials designed to teach children what to do in the task (without biasing them to shape or material responses overall), these trials were done with familiar objects for which children should have some prior knowledge and basis for responding. When the proper test trials started, children were confronted with novel stimuli specifically designed such that they should have more limited knowledge of the individual items. However, by the end of the experiment, they would have completed sixteen trials with novel stimuli, with all the trials following the same repeating structure, of familiarisation, naming and response, and with sets of trials that repeated the exemplar and test objects seen. Thus, by the end of the experiment, children had a much better idea of the "game", and because they knew that the experimenter would name an object and ask them to pick one by name, they might be (literally) looking ahead to the object that they would eventually choose, even before the name has occurred. We did not pursue examination of such effects in Chapter 4, based on not finding evidence of an effect of trial number when analysing the data reported in Chapter 2. However, it is possible a more careful examination of these data might reveal such an effect.

An alternative, and not mutually exclusive, possible source of the effect in Chapter 4 and the difference in findings between the two chapters has to do with a critical difference between the timing of the two studies; the data reported in Chapter 2 was collected prior to the COVID-19 pandemic while those reported in Chapter 4, were collected after. The concrete result of this is that there was much more variability in the vocabulary scores of children in sample collected for Chapter 4, and, indeed, a greater number of children who had relatively low productive vocabularies for their age and gender. This can be seen in Figure 5.1, that presents the noun vocabulary by age for the sample from Chapter 2 (circle points and straight lines) and Chapter 4 (tringle points and dashed lines) together. Of note are the three datapoints circled in black in the figure. These circles indicate the three participants whose data were removed from the main analysis in Chapter 2 (and Bakopoulou et al., 2023) because their vocabularies fell more than 1.5 standard deviations from the mean for their age and gender. As reported in Chapter 2, these children showed a different pattern of responding in the novel noun generalisation task, and in particular, looked more to the shape matching test object prior to the naming event. As can be seen when looking at the triangle points of Figure 5.1, many more of the children in Chapter 4's sample were close in range to the children classified as outliers in Chapter 2. Thus, one possible reason for the difference in the reported results across the two chapters is that more children in Chapter 4 had a relatively low vocabulary for their age, and thus were responding more similarly to the outliers in the Chapter 2. This is an interesting possibility as it may point to new insight on the relation between vocabulary and attention to shape in the novel noun generalisation task. Whereas prior work has suggested that it is the number of nouns in the productive vocabulary that is related to production of the bias, it may be that this is also qualified by a third factor that develops relatively to a child's age, perhaps other conceptual developments or other knowledge of categories and objects. Future work that continues to recruit children with a broad spectrum of vocabulary skills will be required to examine this possibility.

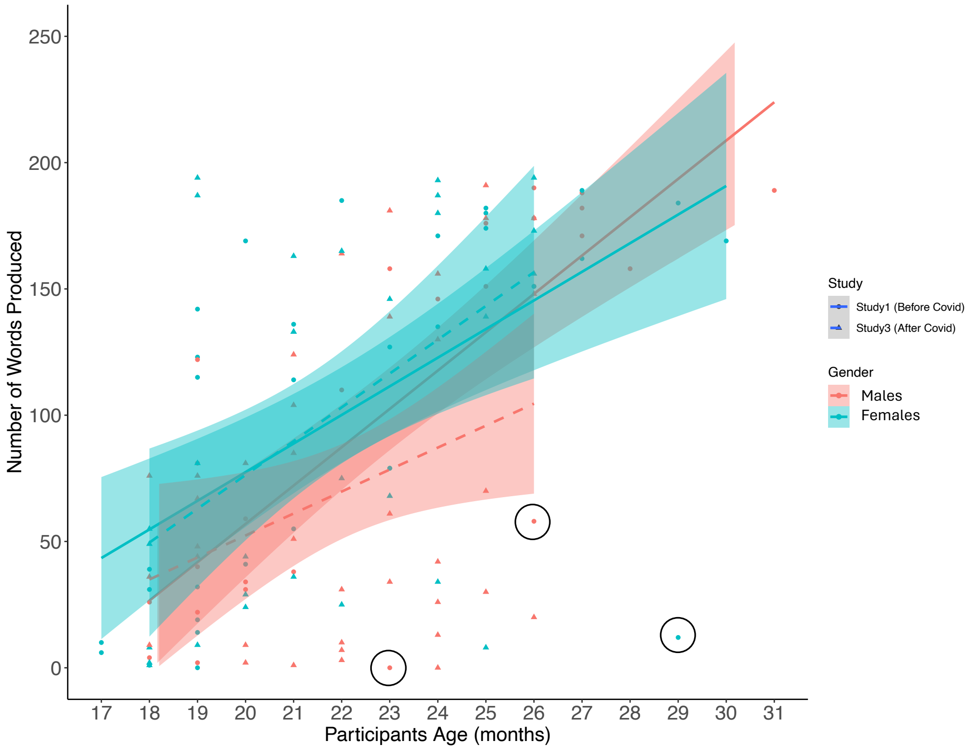

Figure 5.1: The relation between productive noun vocabulary and age for the males (red) and females (blue). The data from sample in Chapter 2 with circle points and from Chapter 4 with triangle points. Shaded regions indicate 1.5 standard deviations of the mean for each gender. The three outlying participants from Chapter 2 are circled in black. Solid line represents Chapter 2 and dashed line represents Chapter 4.

In addition, in both chapters we found that children manually explored all the objects equally before the naming event, indicating they had no preference between them. Concurrently we found that children's looking transitions decreased as vocabulary increased. The naming event stimulated more visual comparison of the objects in children with smaller vocabularies. In Chapter 2 we found a similar pattern with reaction time, which also decreased as vocabulary increased. Thus, children who had more nouns looked to the selected object more quickly and did less comparison of the test objects, while those who had fewer nouns compared the stimuli more. However, in Chapter 4, reaction time also slightly decreased as vocabulary increased, but this change was limited. The difference between the chapters could be due to the fact that there was more variability in the vocabulary scores of children in Chapter 4. The concrete outcome of this is that there was more diversity in the vocabulary scores of children in the sample collected for Chapter 4, as well as a bigger percentage of children who had relatively low productive vocabularies for their age and gender.

Overall, the results above provide an answer to the first research question of how vocabulary development influences children's attention to shape in the novel noun generalisation task. Our findings showed that, early in vocabulary development, children do not automatically direct their attention to shape-matching objects after the naming event. However, as their vocabulary grows, particularly as they learn more nouns, this process becomes increasingly automatic. These data suggested that while children with smaller vocabularies rely on exploratory behaviours, such as shifting their gaze between objects, those with larger vocabularies are more likely to focus on the shape-matching object immediately after the naming event. The automatic link of the naming event for shape-matching stimuli develops alongside vocabulary acquisition. Furthermore, the equal manual exploration prior to the naming event suggests that the shape-matching test object is not automatic early in vocabulary development but rather develops alongside vocabulary expansion.

5.2 Memory for objects

Having established this understanding, that novel words guide children's attention when generalising novel nouns, we turned our focus to children's object memory. Our interest was in considering whether differences in word learning abilities were influenced by memory processes. Thus, the second research question concerned the relation between object memory and vocabulary in children. This question was motivated by the possible explanation for one of our findings from the first study: that the difference in attention when generalising novel nouns might be related to variability in memory processes. In addition, the findings by Collisson et al. (2015), who demonstrated that children with SLI, who did not exhibit a shape bias, performed more poorly on a test of visual object memory, also suggested the possibility that children's memory for objects was related to their vocabulary. Further motivation for this study came from the fact that object memory is critical in the initial stages of learning word–referent pairings, as it helps to anchor new words in the child's memory by associating them to their corresponding objects or concepts. Thus, we examined the relation between children's memory for visual stimuli, as measured by the VPA task, and very early vocabulary development.

In contrast to the work by Collisson et al. (2015) we aimed to understand the relations among memory for objects and early vocabulary. We developed an eye-tracking task for a younger age group, children between 14 and 26 months of age to examine how well children in the early stages of vocabulary development could remember pairs of familiar and novel pictures. We tested memory for both familiar and novel objects to examine whether children's memory for objects depended on whether it was something they had prior knowledge of and, potentially, knew the word for, versus than a completely new object. We found that children were better at remembering pairs of familiar objects than pairs of novel ones. This suggests that children's existing representations of the individual familiar objects enhance memory of those that we paired together. As a result, when we repeated the task in Chapter 4, we removed the novel objects as they were too challenging for the children because they could not remember them. An unexpected finding in the initial dataset from Chapter 3, was that children in the low total vocabulary group showed better object memory compared to children in the high vocabulary group. This was surprising as prior research (e.g., Vlach & DeBrock, 2017; Collisson et al., 2015) suggested that better object memory was associated with better word learning. However, when we analysed the data based on percentiles (taking age and gender into account) we found that children in the high percentile group showed better object memory. We had used the 25th percentile as a cut off in this analysis because in prior research children below the 25th percentile for their age and gender were designated "late talkers" (MacRoy-Higgins & Montemarano, 2016; Perry, Kucker, et al., 2022). The fact that we found children above this cutoff evidenced better object memory thus suggests the data conformed to expectations more when analysed this way.

In the replication of this task, in Chapter 4, we did find a relation between vocabulary and gender in terms of proportion looking to the target. However, following primes associated with that target, children's looking to the target hovered around 50%, suggesting they were not systematically looking to the target and dampening any evidence of a relation between object memory and vocabulary. Thus, there was little indication in these data that object memory had potential relations to vocabulary. Again, the pattern of results was slightly different when the data were analysed by vocabulary groups compared to percentile scores. In particular, we looked at the data for children whose vocabulary was either above or below the 25th percentile. Our results followed a similar format to the results found in Chapter 3 in terms of the significant interactions in the model. However, we did not find that children whose vocabularies were above the 25th percentile for age and gender were able to remember what object they had previously been seen with the probe on associated trials at significant levels. Also, as a group, children below the 25th percentile did not perform as well. The difference between the results from Chapter 3 and 4 could be due to the fact we had to drop data from many trials in Chapter 4 due to the bias to attend to animate objects. Of course, it is interesting that we did not see this problem in the sample collected for Chapter 3. It is possible this, and the generally weaker performance of children in Chapter 4, is due to the fact the vocabulary scores were more variable in sample of children collected for Chapter 4, and thus more children had low vocabularies for their age and gender.

Thus, in terms of overall vocabulary score, the findings from our object memory task were different from those of Vlach and DeBrock (2017), who found that children with larger vocabulary remembered more pairs of objects. In addition, Collisson et al.'s (2015) also found that children older than the sample included here, remembered more pairs of objects in their visual paired associate task. However, there are multiple methodological differences between the prior studies and ours, including as our use of the eye-tracking to allow prolonged monitoring of visual attention rather than asking for discrete responses. Likewise, the previous studies included verbal instructions (Collisson et al., 2015; Vlach & DeBrock, 2017). We removed the verbal instructions to make the task suitable for younger children, and instead hoped that the comparison of looking following an associated probe, that would activate their memory for the object that had previously been seen with that object, versus a random probe that would not have such an association, and would reveal children's object memory abilities. This lack of instruction may have caused confusion, as the children may not have understood what they were to be doing in the task, leading to the complicated patterns of the results observed. It could also be concluded, given the lack of robust findings with the younger children we tested, that children under 26 months have trouble remembering new associations that are presented only once. Earlier studies found children had trouble forming and maintaining associations of novel word-object pairings following brief presentations until they are 30 months old (Bion et al., 2013; Horst & Samuelson, 2008; Kucker & Samuelson, 2012). Thus, it could be that it is not just memory for pairs of objects, but memory for associations that is weak early in vocabulary development.

In contrast, we had weak evidence that children's vocabulary knowledge was related to their ability to remember object pairs, when their relative vocabulary standing is taken into account, at least in our initial data from Chapter 3. Noting that the data from Chapter 4 were compromised by the bias towards animate objects that resulted in the need to eliminate trials that included inanimate and animate objects and significantly reducing our power, we felt we had some suggestions that the task we developed was sensitive to detecting relations between children's relative vocabulary standing (e.g. percentile), rather than absolute number of words known, and memory for visual stimuli. These results also created an argument that total vocabulary score may not be the best measure of object memory. Children with smaller vocabulary showed better object memory than expected. However, our results based on percentiles, adjusted for age and gender, suggest that children in higher percentiles performed better on memory tasks. Therefore, there is a clear possibility that the VPA task might be most sensitive to detecting relations between memory for visual stimuli and children's relative vocabulary (adjusted for age and gender), rather than an absolute number of words known.

5.3 Working memory and retention in word learning

The third research question examined the relation between attention, memory at multiple timescales, and word learning, which was addressed in Chapter 4. Our previous findings from Chapter 3 indicated that object memory was somewhat related to vocabulary, when percentile scores were used as an index of vocabulary, and that attention to shape increased with the number of nouns in children's productive vocabularies. Thus, to investigate relations between attention to object features and object memory children between 18-26 months of age participated in a novel noun generalisation task with an eye tracker and an adapted version of the VPA task (Chapter 3) to test object memory. To be able to answer the third research question we had to also investigate other types of memory rather than just object memory. We introduced tasks to investigate both short- and long-term memory. To capture children's short-term memory, we used the visual working memory (VWM) task and to capture their long-term memory, we used a retention task. Our results revealed that children's retention was not related to their vocabulary as children performed below chance on the retention task in Chapter 4. This contrastsed with some previous research that has suggested a potential relation between vocabulary and retention of names presented in NNG (Lorenz & Kucker, 2021, April). Our results are consistent with Kucker et al. (2023) and Horst and Samuelson (2008), suggesting that children in our sample (aged 18 to 26 months) could not retain word–object mappings, although it should be noted that those studies used a referent selection task, rather than the NNG task used here. One possible reason for the difference between our findings and those of Lorenz and Kucker (2021, April), is that we had many fewer participants overall (68 here compared to 330 in the prior study), and many of the children we tested did not complete all of the retention trials. Indeed, we did find a positive correlation between performance and the number of trials completed. Thus, there is the possibility that if we had more participants and/or more completed trials, the data would have matched prior findings. Alternatively, there is once again, the possibility that the discrepancy between our findings and those reported in the prior literature may be related to the effects of the COVID-19 pandemic and the lower overall vocabulary performance in our sample.

In terms of VWM performance, we found that children who had low shift rate showed strong VWM as their age increased, but specifically only on trials with two objects, suggesting that their visual working memory for up to two items improved as they grew older. However, they were not able to hold more items in their VWM as their age increased. Thus, the capacity seen in our study is lower than prior studies that have found that from 10 to 13 months, infants demonstrate good VWM performance with arrays containing two to three items (Ross-Sheehy et al., 2003). Even though we predicted that there would be a positive association between VWM and vocabulary, following the idea that VWM supports early vocabulary development, this was not seen in our findings. Models relating VWM and vocabulary were not significant. It is possible that the connection between VWM and word learning would emerge as children grow older. There is also an interesting possibility that the lack of relation between vocabulary and VWM could be related to the fact that we had many children with lower vocabulary for their age in this sample, which may reflect an effect of the COVID-19 pandemic. The lack of a relation between our measure of VWM and age in the children with high shift rates is also striking. One possibility is that the rapid gaze shifts could point towards attentional challenges, resulting in limited fixation durations.

5.4 Overall relations between Word-Learning Processes, Retention and Visual Memory Systems

Our results revealed relations between children's attention to objects when learning new nouns and memory abilities at multiple timescales. Our goal was to understand whether there is any relation between the shape bias, VWM, retention, object memory and vocabulary. Using the results from Chapter 4, in which the children took part in all the different tasks, we were able to investigate potential relations among them. However, we found fewer relations between children's abilities and their vocabulary than we had expected. Contrary to Collisson et al. (2015) we did not find a relation between object memory and the shape bias, as children with better object memory did not show more attention to shape bias when generalising novel nouns. Also, we did not find a relation between children's object memory and retention as children who had better object memory were not able to retain more word-object mappings from the NNG task. However, given that the object memory data may not be particularly robust, and we have a small number of retention trials completed, caution is needed in interpreting these results. Surprisingly, we also did not find the expected relation between better attention to shape and better retention as children could not remember the word-object mapping presented in the naming portion of the NNG task. This is contradictory to research findings by Lorenz and Kucker (2021, April), who found that children show retention of mappings presented in NNG, but as discussed previously, there are other factors that could influence these findings. However, we did find a relation between VWM and retention, particularly showing that children with stronger VWM could retain more new object names. This was seen as stronger working memory was related to better retention of names presented ostensively in the NNG task. This suggests that VWM plays a critical role in how children store and manage new information, allowing them to hold on to representations of objects for longer periods. It links with the idea that older infants with better visual working memory likely possess enhanced long-term memory capabilities (Forsberg et al., 2023). Conversely, younger children or those with smaller vocabularies may have weaker LTM mechanisms for word-object mappings (Schurgin, 2018) and thus rely more heavily on the strength of their VWM to process and encode these mappings.

We also found that, contrary to our predictions, better performance on the VWM task is related to *more* transitions in the NNG task, as overall higher values on our measure of working memory (proportion looking to the change side) were associated with more transitions in the NNG task. This relation was also stronger for children who had lower shift rates in the VWM task. Thus, it does not seem that our proposal from Chapter 2, that children with lower vocabulary transitioned more between the objects in the NNG task because they could not maintain a working memory of the objects, is correct. Additionally, we did not find that the speed to make a noun generalisation decision (e.g., children's reaction time), was related to our measures of VWM.

We did find that vocabulary influenced the relation between VWM and retention. Specifically, children with a smaller vocabulary evidenced a positive relation between VWM performance and retention. Children with a larger vocabulary did not evidence a relation between VWM and retention, however. Thus, it can be concluded that stronger visual working memory is related to retention of names presented ostensively in the NNG task, for children with smaller vocabularies. This suggests that for children with poorer vocabulary enhancing VWM could be a way to support language development and retention of new words. The role of memory, particularly visual memory, is crucial in children's word learning, as it supports the encoding, retention and recall of word–object associations (Pickering et al., 2023). This indicates that interventions aimed at improving VWM could enhance word retention and retrieval, facilitating language acquisition. This could be taken a step further to suggest that children with better working memory skills would perform better academically over time by emphasising that early cognitive abilities significantly influence later academic success (Bull et al., 2008).

5.5 Early Word Learning insights into Late Talkers

Another finding in the current work is that children with slower vocabulary growth showed a different pattern of visual exploration and noun generalisation than children who are learning words at a more typical pace. In Chapter 2, we had three outliers whose vocabulary was three standard deviations from the rest of the sample. These children would meet the criterion of being classified as "late talkers" in some studies. Interestingly, these three outliers demonstrated shape bias as their shape choices were well above chance level. They also showed a slightly different pattern of visual exploration in the novel noun generalisation task. In particular, these children appeared to look equally to the exemplar- and shape-matching test object before the naming event (rather than equally to the two test objects as seen in the results from the typically developing children). After the naming event, these children looked more to the shape-matching test object, although some attention to the material-matching test object could also be seen (Figure 2.3, Chapter 2). These children also appeared to have transitioned between the objects before making their generalisation selections more than children in the main sample, suggesting they required more comparison of the objects before they could make their generalisation decision. The bias to look at the shape-matching test once the generalisation trial proper began, but before the naming event, suggests the possibility that for these three outlying children, it is something other than the naming event itself, that was directing their attention to the shape-matching test object. We had no such clear outliers in Chapter 4, because overall there was much more variability in the vocabulary development of that sample. But interestingly, we saw that the looking behaviour of sample in Chapter 4 evidenced some similarities to the outliers from Chapter 2. In particular, there was some evidence of looking to the shape matching test object before the naming event in Chapter 4. Thus, our work adds to the literature suggesting that late talkers show differences in their word learning abilities. For example, both Perry and Kucker (2019) and Colunga and Sims (2012) have examined the relation between that children's vocabulary composition and their performance in NNG tasks. Perry and Kucker (2019), demonstrated that late-talkers showed reduced efficiency in using shape as a cue to generalise new words to objects, suggesting that their word learning strategies might rely less on shape information compared to TD children. This was not seen in our data as we found that these children showed shape bias more than expected given the small size of their vocabulary. However, Colunga and Sims (2012), trained computational models to produce word learning biases based on the vocabularies of typical and late-talking children. They found that models trained on vocabularies from late talkers attended to shape too much, showing a shape bias for solids that was over-generalised to non-solids. Thus, there is some prior evidence that the vocabularies of late talkers may lead them to strong attention to shape, similar to the behaviour of the three children who were outliers in our Chapter 2 sample. This also relates Perry, Kucker, et al.'s (2022) finding that children diagnosed with DLD between the ages of four and seven years had a significantly smaller proportion of shape-based nouns in their toddler vocabulary than TD children and children with other diagnoses, such as dyslexia. These data suggest it could have been interesting to analyse the vocabulary composition of our outliers in Chapter 2, or in the sample from Chapter 4, and relate those data to attention to shape in the NNG.

5.6 Summary of findings

Taken together, findings across the three studies in this project make four contributions to the literature. The first is related to our measurement of moment-to-moment looking in an NNG task (Chapter 2 and 4). The data presented here suggested that the naming event captured children's attention, but their vocabulary influenced whether this process was automatic or deliberative. Children with larger vocabularies exhibited a more automatic response, while those with smaller vocabularies engaged in a more deliberate process, comparing stimuli to apply conceptual knowledge in making generalisation decisions. Most of the findings from Chapter, were replicated in Chapter 4 reinforcing the conclusion that children's attention was influenced by their vocabulary. The second contribution to the field stems from the importance that object memory has in children's object mapping (Chapter 3 and 4). The data presented here suggested that children's object memory may relate to their vocabulary, when vocabulary is measured not as absolute number of words produced, but relative to the child's age and gender. This then suggested the possibility that it might be the relative size of the vocabulary in relation to other developments that is related to object memory. However, these findings need to be taken cautiously, given the fact the relation between vocabulary percentile and object memory was not replicated in Chapter 4. The third contribution stems from the examination of memory at multiple timescales in relation to vocabulary development. By collecting data on object memory, longer-term retention of new word-object mappings and visual working memory in the same children at the same timepoint, we were able to examine which memory timescales were related to word learning and which were not. Unfortunately, our ability to draw firm conclusions about relations between vocabulary and object memory was hampered by the lack of robust findings across both our VPA tasks. However, we did see some relations when considering VWM, retention and vocabulary. The data presented here suggested that children's visual working memory (VWM) is related to their age, not their vocabulary, and that longer-term retention of new names may be related to the number of words children produce. However, we did find a relation between retention of novel names, vocabulary, *and* VWM. Specifically, for the children in our sample with smaller vocabularies, better retention was associated with better VWM performance. Interestingly, this relation did not hold for the children in our sample who knew more words. Thus, we have some evidence that VWM is related to vocabulary development, at least at some stages of the process. A fourth contribution stems from an unplanned circumstance that influenced this thesis due to COVID-19 as one study that examined novel noun generalisation was carried out prior and one after the pandemic. This difference between the samples collected enabled a broader view of the relation between vocabulary and attention to shape when generalising novel nouns. The sample collected after COVID-19 showed much more variability in their vocabulary scores, and in particular, included a greater number of children who had relatively low productive vocabularies for their age and gender. While we did see that demonstration of the shape bias was related to the number of nouns in the productive vocabulary, the sample overall still showed a shape bias. Given the relatively low vocabularies of many of these children, these data suggested the possibility that demonstration of the bias might be qualified by a third factor that develops relative to a child's age, perhaps other conceptual developments or other knowledge of categories and objects. Examining this possibility would require more studies that collect data from children with a wide range of vocabulary abilities.

5.7 Limitations and future directions

A key highlight of this thesis is our use of the standard measure for assessing shape bias, the NNG task, which we further enhanced by incorporating measurement of moment-by-moment looking, first through hand-coding and later by collecting eye-tracking data – an approach, to our knowledge, never attempted before. This advancement refined the original NNG task. The use of the eye-tracker allowed us to automate fine-grained measures of children's looking patterns, providing a more detailed investigation of their looking dynamics when generalising novel nouns. However, some participants leaned too close to the tracker while pointing to indicate their response which resulted in loss of track that was not recovered. Finding a potential solution in future research such as using an automatic re-calibration when the eye tracker detects that the children have moved out of the tracking range and finding a wider range of acceptable tracking distances, could reduce eye tracking data loss. Another limitation of the current work is the lack of robust findings from our visual paired associate task, that we used as a measure of object memory.

A possible adaptation to make our VPA task stronger lies in studies examining how young language learners encounter visual objects. The way children visually process objects in their environment could play a significant role in vocabulary acquisition, influencing their ability to remember those objects. Knabe and Vlach (2023) suggested context influences children's language learning. In their task they included a learning phase, where children viewed six animated videos. Participants were presented constant pairings of new objects, characters, and scenes. Every scene began with a target and a distracting object on view, then two people from opposing sides of the screen entered each scene appearing for three seconds. The characters' entrance points were set to provide equal screen time. Twelve seconds into the trial, there were three sentences involving two mentions of the target object. The target characters said the name of the object, they started describing it as well as pointing to it during the final sentence. After the conversation ended, the target object spun for two seconds. Participants' visual attention was tracked across the 23-second scenario. In the testing phase children were presented with six forced-choice recognition trials for six categories of associations: word-object, person-object, scene-object, scene-person, scene-word, and person-word associations. Images were displayed on screen until children selected one of the options. Their results demonstrate that as children built stronger associations for features of the overall scene it seemed to help their vocabulary development and word mapping. The various cues presented in their study generated associations, such as between words, objects, people, and the broader environmental context. They proposed that the environment may play a critical role for children's vocabulary development. This suggests a way to improve our VPA task, which is by providing context to the visual pairs to examine if that improves children's memory for objects.

In terms of future work, one future direction could be to integrate computational modelling techniques to better understand children's different word learning trajectories. Using formal computational models could be beneficial, especially ones that provide clear insights into how memory and attention processes support visual discovery and how vocabulary affects these systems. Models like the Word–Object Learning via Visual Exploration in Space (WOLVES) by Bhat et al. (2021), a model of autonomous visual exploration in preferential-looking tasks and word learning for both children and adults, could be used to test predictions about the roles early visual processing, attention and working memory play in word learning. WOLVES could also offer useful tools to generalise VPA tasks across different vocabulary levels, infants' looking behaviours, and their associations and dissociations with objects at different points in the test phase. Another interesting idea for future research would be to track the processes studied here longitudinally. Using the tasks from this study, and similar tasks, to test children's memory attention at multiple timepoints, as well as collect vocabulary at each session, could provide more insight on how relations between attention, memory and vocabulary are changing over time. If collected in enough detail, this could lead to suggested interventions or recommendations for parents on activities to engage in from an early age (see Samuelson, 2021, for a proposal). Further research is needed to better understand how these cognitive capacities interact throughout development, particularly in shaping individual learning trajectories in early childhood. For instance, it could help identify whether specific profiles at 18 months, based on patterns of performance across various tasks, may predict lower academic achievement later on.

5.8 Conclusions

This thesis investigated the roles of attention and memory in children's vocabulary development. It revealed that children's attention, when generalising novel nouns. Transitions from being deliberative to being automatic, as the early vocabulary grows. Additionally, this research highlighted that the size of a child's vocabulary relative to their age and gender may relate to their object memory. It also suggested that memory abilities at different timescales relate to word learning in different ways: Retention of names presented ostensively was not related to the absolute number of words in the productive vocabulary, but VWM was related to children's age. Lastly, the findings showed relations between visual working memory and attention to object properties as well as visual working memory and better retention, but only for children with smaller vocabularies. Thus, the data provided insight on how attention, memory and word learning are related, and are not related in early development.

References

Abdelaziz, A., Kover, S. T., Wagner, M., & Naigles, L. R. (2018). The shape bias in children with autism spectrum disorder: Potential sources of individual differences. *Journal of Speech, Language, and Hearing Research (JSLHR)*, *61*(11), 2685–2702. doi: 10.1044/2018_JSLHR-L-RSAUT-18-0027

Abney, D. H., Suanda, S. H., Smith, L. B., & Yu, C. (2020). What are the building blocks of parent–infant coordinated attention in free-flowing interaction? *Infancy*, *25*, 871-887. doi: 10.1111/infa.12365

Acheson, D. J., & MacDonald, M. C. (2009). Verbal working memory and language production: Common approaches to the serial ordering of verbal information. *Psychological Bulletin*, *135*, 50-68. doi: 10.1037/a0014411

Althaus, N., & Mareschal, D. (2014). Labels direct infants' attention to commonalities during novel category learning. *PLoS ONE*, *9*(7), e99670. doi: 10.1371/journal.pone.0099670

Aneja, P. (2022). *Lab and lounge: Relating measures of visual working memory from naturalistic to laboratory setting in rural india* (Doctoral thesis, University of East Anglia). Retrieved from https://ueaeprints.uea.ac.uk/id/eprint/92577/

Archibald, L. M. (2017). Working memory and language learning: A review. *Child Language Teaching and Therapy*, *33*, 5-17. doi: 10.1177/

0265659016654206

Armstrong, R., Scott, J. G., Whitehouse, A. J., Copland, D. A., Mcmahon, K. L., & Arnott, W. (2017). Late talkers and later language outcomes: Predicting the different language trajectories. *International Journal of Speech-Language Pathology*, *19*, 237-250. doi: 10.1080/17549507.2017.1296191

Aslin, R. N. (2017). Statistical learning: A powerful mechanism that operates by mere exposure. *Wiley Interdisciplinary Reviews: Cognitive Science*, *8*(1-2). doi: 10.1002/wcs.1373

Axelsson, E. L., Horst, J., Playford, S., & Winiger, A. I. (2023). Do toddlers rely on a process-of-elimination or a novelty bias in ambiguous word learning contexts? In *Proceedings of the annual meeting of the cognitive science society.* Retrieved from https://escholarship.org/uc/item/2ph5s3br

Baddeley, A. D. (1986). *Working memory.* Oxford: Oxford University Press.

Baddeley, A. D. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology*, *63*, 1-29.

Baddeley, A. D., & Hitch, G. J. (1994). Developments in the concept of working memory. *Neuropsychology*, *8*(4), 485.

Bakopoulou, M., Lorenz, M. G., Forbes, S. H., Tremlin, R., Bates, J., & Samuelson, L. K. (2023). Vocabulary and automatic attention: The relation between novel words and gaze dynamics in noun generalization. *Developmental Science*, *26*. doi: 10.1111/desc.13399

Baldwin, D. A., & Markman, E. M. (1989). Establishing word-object relations: A first step. *Child Development*, *60*(2), 381–398. doi: 10.1111/j.1467-8624.1989.tb02723.x

Bavin, E. L., Wilson, P. H., Maruff, P., & Sleeman, F. (2005). Spatiovisual memory of children with specific language impairment: Evidence for generalized processing problems. *International Journal of Language & Communication Disorders*, *40*(3), 319–332. doi: 10.1080/13682820400027750

Berk, S., & Lillo-Martin, D. (2012). The two-word stage: Motivated by linguistic or cognitive constraints? *Cognitive Psychology*, *65*, 118-140. doi: 10.1016/j.cogpsych.2012.02.002

Bhat, A. A., Spencer, J. P., & Samuelson, L. K. (2021). Word-object learning via visual exploration in space (wolves): A neural process model of cross-situational word learning. *Psychological Review*, *129*, 640-695. doi: 10.1037/rev0000313

Bialystok, E., Peets, K. F., Yang, S., & Luk, G. (2010). Receptive and expressive vocabulary development in children learning english as an additional language: Converging evidence from multiple datasets. *Journal of Child Language*.

Bion, R. A., Borovsky, A., & Fernald, A. (2013). Fast mapping, slow learning: Disambiguation of novel word-object mappings in relation to vocabulary learning at 18, 24, and 30 months. *Cognition*, *126*(1), 39-53.

Bishop, D. V. M. (2017). Why is it so hard to reach agreement on terminology? the case of developmental language disorder (dld). *International Journal of Language & Communication Disorders*, *52*(6), 671–680. doi: 10.1111/1460-6984.12335

Blom, E., & Boerma, T. (2019). Reciprocal relationships between lexical and syntactic skills of children with developmental language disorder and the role of executive functions. *Autism & Developmental Language Impairments*, *4*. doi: 10.1177/2396941519863984

Blom, E., & Boerma, T. (2020). Do children with developmental language disorder (dld) have difficulties with interference control, visuospatial working memory, and selective attention? developmental patterns and the role of severity and persistence of dld. *Journal of Speech, Language, and Hearing Research*, *63*(9), 3036–3050. doi: 10.1044/2020_JSLHR-20-00012

Bobb, S. C., Huettig, F., & Mani, N. (2016). Predicting visual information during sentence processing: Toddlers activate an object's shape before it is mentioned. *Journal of Experimental Child Psychology*, *151*, 51–64. doi: 10.1016/j.jecp.2015.11.002

Booth, A. E., & Waxman, S. R. (2008). Shape bias special section: Taking stock as theories of word learning take shape. *Developmental Science*, *11*, 185-194. doi: 10.1111/j.1467-7687.2007.00664.x

Booth, A. E., Waxman, S. R., & Huang, Y. T. (2005). Conceptual information permeates word learning in infancy. *Developmental Psychology*, *41*(3), 491–505. doi: 10.1037/0012-1649.41.3.491

Borgström, K., von Koss Torkildsen, J., Sahlén, B., & Lindgren, M. (2019). Brain measures of toddlers' shape recognition predict language and cognitive skills at 6–7 years. *Frontiers in Psychology*, *10*, 1-13. doi: 10.3389/fpsyg.2019.01945

Braginsky, M., Yurovsky, D., Marchman, V. A., & Frank, M. C. (2019). Consistency and variability in children's word learning across languages. *Open Mind*, *3*, 52-67. doi: 10.1162/opmi_a_00026

Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., ... Bolker, B. M. (2017). glmmTMB Balances Speed and Flexibility Among Packages for Zero-inflated Generalized Linear Mixed Modeling. *The R Journal*, *9*(2), 378–400. doi: 10.32614/RJ-2017-066

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, *33*, 205-228. doi: 10.1080/87565640801982312

Burnett Heyes, S., Zokaei, N., van der Staaij, I., Bays, P. M., & Husain, M. (2012). Development of visual working memory precision in childhood. *Developmental Science*, *15*(4), 528–539. doi: 10.1111/j.1467-7687.2012.01148.x

Buss, A. T., Fox, N., Boas, D. A., & Spencer, J. P. (2014). Probing the early development of visual working memory capacity with functional near-infrared spectroscopy. *NeuroImage*, *85*(1), 314–325. doi: 10.1016/j.neuroimage.2013.05.034

Buss, A. T., Ross-Sheehy, S., & Reynolds, G. D. (2018). Visual working memory in early development: A developmental cognitive neuroscience perspective. *Journal of Neurophysiology*, *120*, 1472-1483. doi: 10.1152/jn.00087.2018

Carey, S. (1978). *The child as word learner* (M. Halle, J. Bresnan, & G. A. Miller, Eds.). Cambridge, MA: MIT Press.

Carey, S. (2010). Beyond fast mapping. *Language Learning and Development*, *6*(3), 184–205. doi: 10.1080/15475441.2010.484379

Carey, S., & Bartlett, E. (1978). *Acquiring a single new word* (Vol. 15). John Wiley & Sons.

Carvalho, P. F., Vales, C., Fausey, C. M., & Smith, L. B. (2018). Novel names extend for how long preschool children sample visual information. *Journal of Experimental Child Psychology*, *168*, 1-18. doi: 10.1016/j.jecp.2017.12.002

Charman, T., Baron-Cohen, S., Swettenham, J., Baird, G., Cox, A., & Drew, A. (2000). Testing joint attention, imitation, and play as infancy precursors to language and theory of mind. *Cognitive Development*, *15*(4), 481-498.

Cimpian, A., & Markman, E. M. (2005). The absence of a shape bias in children's word learning. *Developmental Psychology*, *41*(6), 1003–1019. doi: 10.1037/0012-1649.41.6.1003

Clerkin, E. M., Hart, E., Rehg, J. M., Yu, C., & Smith, L. B. (2017). Real-world visual statistics and infants' first-learned object names. *Philosophical Transactions of the Royal Society B*, *372*(1711), 20160055.

Coady, J. A., & Evans, J. L. (2008). Uses and interpretations of non-word repetition tasks in children with and without specific language impairments. *International Journal of Language & Communication Disorders*, *43*(1), 1-40.

Collisson, B. A., Grela, B., & Spaulding, T. J. (2015). Visual object memory and language development in children with intellectual disability. *Journal of Speech, Language, and Hearing Research*, *58*(1), 105-117. doi: 10.1044/2014_JSLHR-L-12-0352

Colombo, J., Mitchell, D. W., & Horowitz, F. D. (1988). Infant visual attention in the paired-comparison paradigm: Test-retest and attention-performance relations. *Child Development*, *59*(5), 1198–1210. doi: 10.1111/j.1467-8624.1988.tb01489.x

Colunga, E., & Sims, C. E. (2012). Early-talker and late-talker toddlers and networks show different word learning biases. In *Proceedings of the 34th annual conference of the cognitive science society* (p. 345-353). Boulder, CO, USA: Cognitive Science Society.

Colunga, E., & Sims, C. E. (2017). Not only size matters: Early-talker and late-talker vocabularies support different word-learning biases in babies and networks. *Cognitive Science*, *41*, 73-95. doi: 10.1111/cogs.12409

Colunga, E., & Smith, L. B. (2000). Learning to learn words: A cross-linguistic study of the shape and material biases. In *Proceedings of the 24th annual boston university conference on language development* (Vol. 1, pp. 197–207).

Colunga, E., & Smith, L. B. (2005). From the lexicon to expectations about kinds: A role for associative learning. *Psychological Review*, *112*, 347-382. doi: 10.1037/0033-295X.112.2.347

Colunga, E., & Smith, L. B. (2008). Shape bias special section: Knowledge embedded in process: The self-organization of skilled noun learning. *Developmental Science*, *11*, 195-203. doi: 10.1111/j.1467-7687.2007.00665.x

Cowan, N. (2014). Working memory underpins cognitive development, learning, and education. *Educational Psychology Review*, *26*, 197-223.

DataVyu Team. (2014). *Datavyu: A video coding tool.* In Databrary Project, New York University. (Retrieved from http://www.datavyu.org)

Davidson, D., Rainey, V. R., Vanegas, S. B., & Hilvert, E. (2018). The effects of type of instruction, animacy cues, and dimensionality of objects on the shape bias in 3- to 6-year-old children. *Infant and Child Development*, *27*. doi: 10.1002/icd.2044

Decarli, G., Piazza, M., & Izard, V. (2023). Are infants' preferences in the number change detection paradigm driven by sequence patterns? *Infancy*, *28*, 206-217. doi: 10.1111/infa.12505

de la Cruz-Pavía, I., Marino, C., & Gervain, J. (2021). Learning word order: early beginnings. *Trends in Cognitive Sciences*, *25*, 802-812. doi: 10.1016/j.tics.2021.04.011

Deldar, Z., Gevers-Montoro, C., Khatibi, A., & Ghazi-Saidi, L. (2020). The interaction between language and working memory: a systematic review of fmri studies in the past two decades. *AIMS Neuroscience*, *8*(1), 1–32. doi: 10.3934/Neuroscience.2021001

Delgado Reyes, L., Wijeakumar, S., Magnotta, V. A., Forbes, S. H., & Spencer, J. P. (2020). The functional brain networks that underlie visual working memory in the first two years of life. *NeuroImage*, *219*, 116971. doi: 10.1016/j.neuroimage.2020.116971

DeLoache, J. S., Pickard, M. B., & LoBue, V. (2011). How very young children think about animals. In P. McCardle, S. McCune, J. A. Griffin, & V. Maholmes (Eds.), *How animals affect us: Examining the influences of human–animal interaction on child development and human health* (pp. 85–99). American Psychological Association. doi: 10.1037/12301-004

Diesendruck, G., & Bloom, P. (2003). How specific is the shape bias? *Child Development*, *74*, 168-178. doi: 10.1111/1467-8624.00528

Dockrell, J. E., & Marshall, C. R. (2015). Measurement issues: Assessing language skills in young children. *Child and Adolescent Mental Health*, *20*(2), 116–125.

Donnellan, E., Bannard, C., McGillion, M. L., Slocombe, K. E., & Matthews, D. (2019). Infants' intentionally communicative vocalisations elicit responses from caregivers and are the best predictors of the transition to language: a longitudinal investigation of infants' vocalisations, gestures, and word production. *Developmental Science*, *23*(1), e12843. doi: 10.1111/desc.12843

Druks, J. (2002). Verbs and nouns—a review of the literature. *Journal of Neurolinguistics*, *15*, 289-315.

Ebert, K. D., & Kohnert, K. (2009). Non-linguistic cognitive treatment for primary language impairment. *Clinical Linguistics and Phonetics*, *23*, 647-664. doi: 10.1080/02699200902998770

Ellis, A. W. (1980). Errors in speech and short-term memory: The effects of phonemic similarity and syllable position. *Journal of Verbal Learning &*

Verbal Behavior, *19*, 624–634.

Elman, J. L. (2008). The shape bias: An important piece in a bigger puzzle. *Developmental Science*, *11*(2), 219–222. doi: 10.1111/j.1467-7687.2007.00669.x

Farabolini, G., Ceravolo, M. G., & Marini, A. (2023). Towards a characterization of late talkers: The developmental profile of children with late language emergence through a web-based communicative-language assessment. *International Journal of Environmental Research and Public Health*, *20*. doi: 10.3390/ijerph20021563

Farivar, R. (2009). Dorsal–ventral integration in object recognition. *Brain Research Reviews*, *61*(2), 144-153.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. doi: 10.3758/bf03193146

Feldmann-Wüstefeld, T. (2021). Neural measures of working memory in a bilateral change detection task. *Psychophysiology*, *58*. doi: 10.1111/psyp.13683

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thal, D. J., Pethick, S. J., ... Stiles, J. (1994). In communicative development larry fenson. *Monographs of the Society for Research in Child Development*, *59*, 174-185.

Fenson, L., Marchman, V., Thal, D., Dale, P., Reznick, J. S., & Bates, E. (2007). Macarthur–bates communicative development inventories: User's guide and technical manual (2nd ed.) [Computer software manual]. Baltimore, MD: Paul H. Brookes.

Fernald, A., & Marchman, V. A. (2012). Individual differences in lexical processing at 18 months predict vocabulary growth in typically developing and late-talking toddlers. *Child Development*, *83*, 203-222. doi: 10.1111/j.1467-8624.2011.01692.x

Fernald, A., Zangl, R., Portillo, A. L., & Marchman, V. A. (2008). Looking while listening: Using eye movements to monitor spoken language comprehension by infants and young children. In I. A. Sekerina, E. M. Fernandez, & H. Clahsen (Eds.), *Developmental psycholinguistics: On-line methods in children's language processing* (pp. 97–135). Amsterdam: John Benjamins.

Feuerstahler, L. M., Luck, S. J., MacDonald, A., & Waller, N. G. (2019). A note on the identification of change detection task models to measure storage capacity and attention in visual working memory. *Behavior Research Methods*, *51*, 1360-1370. doi: 10.3758/s13428-018-1082-z

Fitch, A., Smith, H., Guillory, S. B., & Kaldy, Z. (2016). Off to a good start: The early development of the neural substrates underlying visual working memory. *Frontiers in Systems Neuroscience*, *10*, Article 68. doi: 10.3389/fnsys.2016.00068

Floccia, C. (2017). Data collected with the oxford cdi over a course of 5 years in plymouth babylab, uk. *Journal of Child Language*, *27*, 689-705.

Folke, T., Jacobsen, C., Fleming, S. M., & De Martino, B. (2017). Explicit representation of confidence informs future value-based decisions. *Nature Human Behaviour*, *1*(1), e0002. doi: 10.1038/s41562-016-0002

Forbes, S., Dink, J. W., & Ferguson, B. (2021). *eyetrackingr: An r library for eye-tracking data analysis.* Retrieved from http://www.eyetrackingr.com

Forsberg, A., Adams, E. J., & Cowan, N. (2023). Why does visual working memory ability improve with age: More objects, more feature detail, or both? a registered report. *Developmental Science*, *26*. doi: 10.1111/desc.13283

Forsberg, A., Guitard, D., Adams, E. J., Pattanakul, D., & Cowan, N. (2021). Children's long-term retention is directly constrained by their working memory capacity limitations. *Developmental Science*. doi: 10.1111/desc.13164

Frank, M. C., Braginsky, M., Yurovsky, D., & Marchman, V. A. (2017). Wordbank: An open repository for developmental vocabulary data. *Journal of Child Language*, *44*(3), 677-694.

Friend, M., & Keplinger, M. (2003). An infant-based assessment of early lexicon acquisition. *Behavior Research Methods, Instruments, and Computers*, *35*(2), 302–309. doi: 10.3758/BF03202556

Fry, A. F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science*, *7*(4), 237–241. doi: 10.1111/j.1467-9280.1996.tb00366.x

Gathercole, S. E., & Adams, A. M. (1994). Children's phonological working memory: Contributions of long-term knowledge and rehearsal. *Journal of Memory and Language*, *33*(5), 672-688.

Gathercole, S. E., & Pickering, S. J. (2000). Assessment of working memory in six-and seven-year-old children. *Journal of Educational Psychology*, *92*(2), 377.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology*, *18*(1), 1-16. doi: 10.1002/acp.934

Gelman, S. A., Croft, W., Fu, P., Clausner, T., & Gottfried, G. (1998). Why is a pomegranate an apple? the role of shape, taxonomic relatedness, and prior lexical knowledge in children's overextensions of apple and dog. *Journal of Child Language*, *25*, 267-291. doi: 10.1017/

S0305000998003420

Gentner, D. (1982). Why nouns are learned before verbs: Linguistic relativity versus natural partitioning. In S. K. II (Ed.), *Language development, volume 2: Language, thought and culture* (pp. 301–334). Hillsdale, NJ: Lawrence Erlbaum Associates.

Gershkoff-Stowe, L., & Smith, L. B. (2004). Shape and the first hundred nouns. *Child Development*, *75*(4), 1098–1114. doi: 10.1111/j.1467-8624.2004.00728.x

Gibson, D. J., Congdon, E. L., & Levine, S. C. (2015). The effects of word-learning biases on children's concept of angle. *Child Development*, *86*, 319-326. doi: 10.1111/cdev.12286

Gogate, L. J., Maganti, M., & Laing, K. B. (2013). Maternal naming of object wholes versus parts to preverbal infants: A fine-grained analysis of scaffolding at 6–8 months. *Infant Behavior and Development*, *36*(3), 470-479.

Golinkoff, R. M., Mervis, C. B., & Hirsh-Pasek, K. (1994). Early object labels: The case for a developmental lexical principles framework. *Journal of Child Language*, *21*, 125-155. doi: 10.1017/S0305000900008692

Graf, M. (2006). Coordinate transformations in object recognition. *Psychological Bulletin*, *132*(6), 920–945. doi: 10.1037/0033-2909.132.6.920

Graf-Estes, K. G., Evans, J. L., Alibali, M. W., & Saffran, J. R. (2007). Can infants map meaning to newly segmented words? statistical segmentation and word learning. *Psychological Science*, *18*(3), 254-260.

Graham, S. A., & Diesendruck, G. (2010). Fifteen-month-old infants attend to shape over other perceptual properties in an induction task. *Cognitive Development*, *25*(2), 111–123. doi: 10.1016/j.cogdev.2009.06.002

Gray, S. I., Levy, R., Alt, M., Hogan, T. P., & Cowan, N. (2022). Working memory predicts new word learning over and above existing vocabulary and nonverbal iq. *Journal of Speech, Language, and Hearing Research*, *65*, 1044-1069. doi: 10.1044/2021_JSLHR-21-00397

Gómez, R. L., & Gerken, L. (2000). Infant artificial language learning and language acquisition. *Trends in Cognitive Sciences*, *4*(5), 178–186. doi: 10.1016/s1364-6613(00)01467-4

Haaf, R. A., Fulkerson, A. L., Jablonski, B. J., Hupp, J. M., Shull, S. S., & Pescara-Kovach, L. (2003). Object recognition and attention to object components by preschool children and 4-month-old infants. *Journal of Experimental Child Psychology*, *86*(2), 108–123. doi: 10.1016/S0022-0965(03)00108-5

Hamilton, A., Plunkett, K., & Schafer, G. (2000). Infant vocabulary development assessed with a british communicative development inventory. *Journal of Child Language*, *27*(3), 689–705. doi: 10.1017/S0305000900004414

Hart, C. M., & Curtin, S. (2023). Trajectories of vocabulary development in children with autism spectrum disorder across multiple measures. *Journal of Autism and Developmental Disorders*, *53*(4), 1347–1362. doi: 10.1007/s10803-021-05379-w

Hartig, F. (2022). Dharma: Residual diagnostics for hierarchical (multi-level / mixed) regression models [Computer software manual]. Retrieved from https://CRAN.R-project.org/package=DHARMa (R package version 0.4.6)

Hay, J. F., Pelucchi, B., Estes, K. G., & Saffran, J. R. (2011). Linking sounds to meanings: Infant statistical learning in a natural language. *Cognitive Psychology*, *63*(2), 93-106. doi: 10.1016/j.cogpsych.2011.08.002

Henrichs, J., Rescorla, L., Schenk, J. J., Schmidt, H. G., Jaddoe, V. W., Hofman, A., ... Tiemeier, H. (2011). Examining continuity of early expressive vocabulary development: The generation r study. *Journal of Speech, Language, and Hearing Research (JSLHR)*, *54*(3), 854–869. doi: 10.1044/1092-4388(2010/09-0255)

Hills, T. T., Maouene, J., Riordan, B., & Smith, L. B. (2010). The associative structure of language: Contextual diversity in early word learning. *Journal of Memory and Language*, *63*, 259-273. doi: 10.1016/j.jml.2010.06.002

Hitch, G. J., Woodin, M. E., & Baker, S. (1989). Visual and phonological components of working memory in children. *Memory and Cognition*, *17*, 175-185.

Hoff, E. (2003). Language development in childhood. In R. M. Lerner, M. A. Easterbrooks, & J. Mistry (Eds.), *Handbook of psychology: Developmental psychology* (Vol. 6, p. 171-193). John Wiley & Sons, Inc. doi: 10.1002/0471264385.wei0607

Hoff, E. (2006). How social contexts support and shape language development. *Developmental Review*, *26*(1), 55-88.

Horst, J. S. (2013). Context and repetition in word learning. *Frontiers in Psychology*, *4*. doi: 10.3389/fpsyg.2013.00149

Horst, J. S., & Hout, M. C. (2016). The novel object and unusual name (noun) database: A collection of novel images for use in experimental research. *Behavior Research Methods*, *48*, 1393-1409. doi: 10.3758/s13428-015-0647-3

Horst, J. S., & Samuelson, L. K. (2008). Fast mapping but poor retention by 24-month-old infants. *Infancy*, *13*, 128-157. doi: 10.1080/15250000701795598

Horst, J. S., Samuelson, L. K., Kucker, S. C., & McMurray, B. (2011). What's new? children prefer novelty in referent selection. *Cognition*, *118*, 234-

244. doi: 10.1016/j.cognition.2010.10.015

Houston-Price, C., Caloghiris, Z., & Raviglione, E. (2010). Language experience shapes the development of the mutual exclusivity bias. *Infancy*, *15*, 125-150. doi: 10.1111/j.1532-7078.2009.00009.x

Hunnius, S. (2007). The early development of visual attention and its implications for social and cognitive development. *Progress in Brain Research*, *164*, 187-209. doi: 10.1016/S0079-6123(07)64010-2

Huttenlocher, J., Newcombe, N., & Vasilyeva, M. (1999). Spatial scaling in young children. *Psychological Science*, *10*(5), 393–398. doi: 10.1111/1467-9280.00175

Jackson, E., Leitão, S., Claessen, M., & Boyes, M. (2021). Word learning and verbal working memory in children with developmental language disorder. *Autism and Developmental Language Impairments*, *6*. doi: 10.1177/23969415211004109

James, K. H., Jones, S. S., Smith, L. B., & Swain, S. N. (2014). Young children's self-generated object views and object recognition. *Journal of Cognition and Development*, *15*, 393-401. doi: 10.1080/15248372.2012.749481

Jayaraman, S., & Smith, L. B. (2020). The infant's visual world: The everyday statistics for visual learning. In J. J. Lockman & C. S. Tamis-LeMonda (Eds.), *The cambridge handbook of infant development: Brain, behavior, and cultural context* (pp. 549–575). Cambridge University Press. doi: 10.1017/9781108351959.020

Jones, S. S. (2003). Late talkers show no shape bias in a novel name extension task. *Developmental Science*, *6*, 477-483. doi: 10.1111/1467-7687.00304

Jones, S. S., & Smith, L. B. (1993). The place of perception in children's concepts. *Cognitive Development*, *8*(2), 113-139.

Jones, S. S., & Smith, L. B. (2005). Object name learning and object perception:

A deficit in late talkers. *Journal of Child Language, 32*, 223-240. doi: 10.1017/S0305000904006646

Jusczyk, P. W. (1999). How infants begin to extract words from speech. *Trends in Cognitive Sciences*, *3*(9), 323-328.

Kalashnikova, M., Escudero, P., & Kidd, E. (2018). The development of fast-mapping and novel word retention strategies in monolingual and bilingual infants. *Developmental Science*, *21*(6), e12674.

Karmiloff, K., & Karmiloff-Smith, A. (2009). *Pathways to language: From fetus to adolescent*. Cambridge, MA: Harvard University Press.

Keates, J., & Graham, S. A. (2008). Category markers or attributes: Why do labels guide infants' inductive inferences? *Psychological Science*, *19*(12), 1287–1293. doi: 10.111

Keil, F. C. (2008). Shape bias special section commentaries: The shape of things to come: The future of the shape bias controversy. *Developmental Science, 11*, 216-219. doi: 10.1111/j.1467-7687.2007.00668.x

Kidd, E., Arciuli, J., Christiansen, M. H., & Smithson, M. (2023). The sources and consequences of individual differences in statistical learning for language development. *Cognitive Development*, *66*. doi: 10.1016/j.cogdev.2023.101335

Kidd, E., & Donnelly, S. (2020). Individual differences in language acquisition. *Annual Review of Linguistics*, *6*, 319–340. doi: 10.1146/annurev-linguistics-011619-030326

Klee, T., & Harrison, C. (2001). *Cdi words and sentences: Validity and preliminary norms for british english.* (Unpublished manuscript)

Knabe, M. L., & Vlach, H. A. (2023). Not all is forgotten: Children's associative matrices for features of a word learning episode. *Developmental Science, 26*. doi: 10.1111/desc.13291

Kucker, S. C., Braun, B. E., & Markham-Anderson, J. F. (2023). Margarita glasses and high heels: How attention to shape, age, and vocabulary impacts children's recognition of typical and atypical exemplars. *Child Development*, *94*, 603-616. doi: 10.1111/cdev.13883

Kucker, S. C., McMurray, B., & Samuelson, L. K. (2018). Too much of a good thing: How novelty biases and vocabulary influence known and novel referent selection in 18-month-old children and associative learning models. *Cognitive Science*, *42*, 463-493. doi: 10.1111/cogs.12610

Kucker, S. C., & Samuelson, L. K. (2012). The first slow step: Differential effects of object and word-form familiarization on retention of fast-mapped words. *Infancy*, *17*(3), 295-323.

Kucker, S. C., Samuelson, L. K., Perry, L. K., Yoshida, H., Colunga, E., Lorenz, M. G., & Smith, L. B. (2019). Reproducibility and a unifying explanation: Lessons from the shape bias. *Infant Behavior and Development*, *54*, 156-165. doi: 10.1016/j.infbeh.2018.09.011

Kudo, M. F., Lussier, C. M., & Swanson, H. L. (2015). Reading disabilities in children: A selective meta-analysis of the cognitive literature. *Research in Developmental Disabilities*, *40*, 51-62. doi: 10.1016/j.ridd.2015.01.002

Landau, B., Smith, L. B., & Jones, S. (1992). Syntactic context and the shape bias in children's and adults' lexical learning. *Journal of Memory and Language*, *31*, 807-825. doi: 10.1016/0749-596X(92)90040-5

Landau, B., Smith, L. B., & Jones, S. S. (1988). The importance of shape in early lexical learning. *Cognitive Development*, *3*(3), 299–321. doi: 10.1016/0885-2014(88)90014-7

Leckey, S., Selmeczy, D., Kazemi, A., Johnson, E. G., Hembacher, E., & Ghetti, S. (2020). Response latencies and eye gaze provide insight on how toddlers gather evidence under uncertainty. *Nature Human Behaviour*, *4*(9), 928–936. doi: 10.1038/s41562-020-0913-y

Lewis, T. L., & Maurer, D. (2005). Multiple sensitive periods in human visual development: Evidence from visually deprived children. *Developmental Psychobiology*, *46*(3), 163–183. doi: 10.1002/dev.20055

Lloyd-Fox, S., Blasi, A., McCann, S., Rozhko, M., Katus, L., Mason, L., & Elwell, C. E. (2019). Habituation and novelty detection fnirs brain responses in 5- and 8-month-old infants: The gambia and uk. *Developmental Science*, *22*(5), e12817.

Lorenz, M., & Kucker, S. C. (2021, April). Exploration facilitates retention during novel noun generalization. In *Proceedings of the biennial meeting of the society for research in child development.* Minneapolis, MN. (Paper symposium chaired by S.C. Kucker and M. Lorenz. Held virtually due to COVID-19.)

Luck, S. J., & Vogel, E. K. (1997). The capacity of visual working memory for features and conjunctions. *Nature*, *390*(6657), 279–281. doi: 10.1038/36846

Lum, J. A., Conti-Ramsden, G., Page, D., & Ullman, M. T. (2012). Working, declarative and procedural memory in specific language impairment. *Cortex*, *48*, 1138-1154. doi: 10.1016/j.cortex.2011.06.001

MacRoy-Higgins, M., & Montemarano, E. A. (2016). Attention and word learning in toddlers who are late talkers. *Journal of Child Language*, *43*, 1020-1037. doi: 10.1017/S0305000915000379

Marchman, V. A., & Fernald, A. (2008). Speed of word recognition and vocabulary knowledge in infancy predict cognitive and language outcomes in later childhood: Fast-track report. *Developmental Science*, *11*(3), 9-16.

Maris, E., & Oostenveld, R. (2007). Nonparametric statistical testing of eegand meg-data. *Journal of Neuroscience Methods, 164*(1), 177-190. (Epub 2007 Apr 10) doi: 10.1016/j.jneumeth.2007.03.024

Markman, E. M. (1990). Constraints children place on word meanings. *Cognitive Science, 14*, 57-77. doi: 10.1207/s15516709cog1401_4

Markman, E. M. (1994). Constraints on word meaning in early language acquisition. *Lingua, 92*, 199-227.

Markman, E. M., & Hutchinson, J. E. (1984). Children's sensitivity to constraints on word meaning: Taxonomic versus thematic relations. *Cognitive psychology, 16*, 27.

Markman, E. M., & Wachtel, G. F. (1988). Children's use of mutual exclusivity to constrain the meanings of words. *Cognitive Psychology, 20*(2), 121-157.

Markson, L., Diesendruck, G., & Bloom, P. (2008). Shape bias special section: The shape of thought. *Developmental Science, 11*, 204-208. doi: 10.1111/j.1467-7687.2007.00666.x

Mather, E. (2013). Novelty, attention, and challenges for developmental psychology. *Frontiers in Psychology, 4*. doi: 10.3389/fpsyg.2013.00491

Mather, E., & Plunkett, K. (2009). Learning words over time: The role of stimulus repetition in mutual exclusivity. *Infancy, 14*, 60-76. doi: 10.1080/15250000802569702

Mather, E., & Plunkett, K. (2011). Mutual exclusivity and phonological novelty constrain word learning at 16 months. *Journal of child language, 38*, 933-950. doi: 10.1017/S0305000910000401

Mather, E., & Plunkett, K. (2012). The role of novelty in early word learning. *Cognitive Science, 36*, 1157-1177. doi: 10.1111/j.1551-6709.2012.01239.x

Mayor, J., & Plunkett, K. (2011). A statistical estimate of infant and toddler vocabulary size from cdi analysis. *Developmental Science*, *14*, 769-785. doi: 10.1111/j.1467-7687.2010.01024.x

McAfoose, J., & Baune, B. T. (2009). Exploring visual-spatial working memory: A critical review of concepts and models. *Neuropsychology Review*, *19*, 130-142. doi: 10.1007/s11065-008-9063-0

McGillion, M., Herbert, J. S., Pine, J., Vihman, M., DePaolis, R., Keren-Portnoy, T., & Matthews, D. (2017). What paves the way to conventional language? the predictive value of babble, pointing, and socioeconomic status. *Child Development*, *88*(1), 156-166.

McGregor, K. K., Goffman, L., Van, H. A. O., Hogan, T. P., & Finestack, L. H. (2020). Developmental language disorder: Applications for advocacy, research, and clinical service. *Perspectives of the ASHA Special Interest Groups*, *5*(1), 38–46. doi: 10.1044/2019_PERSP-19-00083

McGregor, K. K., Smolak, E., Jones, M., Oleson, J., Eden, N., Arbisi-Kelm, T., & Pomper, R. (2022). What children with developmental language disorder teach us about cross-situational word learning. *Cognitive Science*, *46*(2), e13094.

McMurray, B., Horst, J. S., & Samuelson, L. K. (2012). Word learning emerges from the interaction of online referent selection and slow associative learning. *Psychological Review*, *119*(4), 831–877. doi: 10.1037/a0029872

Mirman, D. (2014). *Growth curve analysis and visualization using r*. Chapman and Hall/CRC.

Morgan, P. L., Farkas, G., Hillemeier, M. M., Hammer, C. S., & Maczuga, S. (2015). 24-month-old children with larger oral vocabularies display greater academic and behavioral functioning at kindergarten entry. *Child Development*, *86*(5), 1351-1370.

Moser, D. A., Doucet, G. E., Ing, A., Dima, D., Schumann, G., Bilder, R. M.,

& Frangou, S. (2018). An integrated brain–behavior model for working memory. *Molecular Psychiatry*, *23*(10), 1974–1980. doi: 10.1038/mp.2017.247

Mourgues, C., Tan, M., Hein, S., Ojanen, E., Reich, J., Lyytinen, H., & Grigorenko, E. L. (2016). Paired associate learning tasks and their contribution to reading skills. *Learning and Individual Differences*, *46*, 54-63. doi: 10.1016/j.lindif.2014.12.003

Mundy, P., Block, J., Delgado, C., Pomares, Y., Van Hecke, A. V., & Parlade, M. V. (2007). Individual differences and the development of joint attention in infancy. *Child Development*, *78*(3), 938–954. doi: 10.1111/j.1467-8624.2007.01042.x

Naigles, L. R., & Tek, S. (2017). 'form is easy, meaning is hard' revisited: (re) characterizing the strengths and weaknesses of language in children with autism spectrum disorder. *Wiley Interdisciplinary Reviews: Cognitive Science*, *8*. doi: 10.1002/wcs.1438

Ngo, C. T., Newcombe, N. S., & Olson, I. R. (2018). The ontogeny of relational memory and pattern separation. *Developmental Science*, *21*(2). doi: 10.1111/desc.12556

Oakes, L. M. (2012). Advances in eye tracking in infancy research. *Infancy*, *17*(1), 1-8. (Epub 2011 Nov 1) doi: 10.1111/j.1532-7078.2011.00101.x

Oakes, L. M., Ross-Sheehy, S., & Luck, S. J. (2006). Rapid development of feature binding in visual short-term memory. *Psychological Science*, *17*(9), 781–787. doi: 10.1111/j.1467-9280.2006.01782.x

Obeid, R., & Brooks, P. J. (2018). Associations between manual dexterity and language ability in school-age children. *Language, Speech, and Hearing Services in Schools*, *49*(4), 982-994. doi: 10.1044/2018_lshss-17-0124

Pelphrey, K. A., & Reznick, J. S. (2003). Working memory in infancy. *Advances* *in Child Development and Behavior*, *31*, 173–227. doi: 10.1016/s0065-2407(03)31005-5

Pereira, A. F., & Smith, L. B. (2009). Developmental changes in visual object recognition between 18 and 24 months of age. *Developmental Science*, *12*, 67-80. doi: 10.1111/j.1467-7687.2008.00747.x

Pereira, A. F., Smith, L. B., & Yu, C. (2014). A bottom-up view of toddler word learning. *Psychonomic Bulletin & Review*, *21*(1), 178–185. doi: 10.3758/s13423-013-0466-4

Perry, L. K., Axelsson, E. L., & Horst, J. S. (2016). Learning what to remember: Vocabulary knowledge and children's memory for object names and features. *Infant and Child Development*, *25*, 247-258. doi: 10.1002/icd.1933

Perry, L. K., Custode, S. A., Fasano, R. M., Gonzalez, B. M., & Valtierra, A. M. (2022). Coordination of caregiver naming and children's exploration of solid objects and nonsolid substances. *Frontiers in Psychology*, *13*. doi: 10.3389/fpsyg.2022.945664

Perry, L. K., & Kucker, S. C. (2019). The heterogeneity of word learning biases in late-talking children. *Journal of Speech, Language, and Hearing Research*, *62*, 554-563. doi: 10.1044/2019_JSLHR-L-ASTM-18-0234

Perry, L. K., Kucker, S. C., Horst, J. S., & Samuelson, L. K. (2022). Late bloomer or language disorder? differences in toddler vocabulary composition associated with long-term language outcomes. *Developmental Science*. doi: 10.1111/desc.13342

Perry, L. K., & Lupyan, G. (2014). The role of language in multi-dimensional categorization: Evidence from transcranial direct current stimulation and exposure to verbal labels. *Brain and Language*, *135*, 66-72. doi: 10.1016/j.bandl.2014.05.005

Perry, L. K., & Saffran, J. R. (2017). Is a pink cow still a cow? individual differences in toddlers' vocabulary knowledge and lexical representations. *Cognitive Science*, *41*(4), 1090-1105.

Perry, L. K., & Samuelson, L. K. (2011). The shape of the vocabulary predicts the shape of the bias. *Frontiers in Psychology*, *2*, 1-12. doi: 10.3389/fpsyg.2011.00345

Perry, L. K., Samuelson, L. K., Malloy, L. M., & Schiffer, R. N. (2010). Learn locally, think globally: Exemplar variability supports higher-order generalization and word learning. *Psychological Science*, *21*, 1894-1902. doi: 10.1177/0956797610389189

Petruccelli, N., Bavin, E. L., & Bretherton, L. (2012). Children with specific language impairment and resolved late talkers: Working memory profiles at 5 years. *Journal of Speech, Language, and Hearing Research*, *55*, 1690-1703. doi: 10.1044/1092-4388(2012/11-0288)

Pickering, H. E., Peters, J. L., & Crewther, S. G. (2023). A role for visual memory in vocabulary development: a systematic review and meta-analysis. *Neuropsychology Review*, *33*(4), 803-833.

Poli, F., Ghilardi, T., Beijers, R., de Weerth, C., Hinne, M., Mars, R. B., & Hunnius, S. (2024). Individual differences in processing speed and curiosity explain infant habituation and dishabituation performance. *Developmental Science*, *27*. doi: 10.1111/desc.13460

Potrzeba, E., Fein, D., & Naigles, L. (2015). Investigating the shape bias in typically developing children and children with autism spectrum disorders. *Frontiers in Psychology*, *6*, 1-12. doi: 10.3389/fpsyg.2015.00446

Quine, W. V. O. (1960). *Word and object*. Cambridge, MA: MIT Press.

R Core Team. (2017). R: A language and environment for statistical computing [Computer software manual]. Vienna, Austria. Retrieved from https://www.R-project.org/

Rescorla, L. (2011). Late talkers: Do good predictors of outcome exist? *Developmental Disabilities Research Reviews*, *17*(2), 141-150.

Rescorla, L., & Achenbach, T. M. (2002). Use of the language development survey (lds) in a national probability sample of children 18 to 35 months old. *Journal of Speech, Language, and Hearing Research (JSLHR)*, *45*(4), 733–743. doi: 10.1044/1092-4388(2002/059)

Rescorla, L., Roberts, J., & Dahlsgaard, K. (1997). Late talkers at 2. *Journal of Speech, Language, and Hearing Research*, *40*(3), 556–566. doi: 10.1044/jslhr.4003.556

Reynolds, G. D. (2015). Infant visual attention and object recognition. *Behavioural Brain Research*, *285*, 34-43. doi: 10.1016/j.bbr.2015.01.015

Riggs, K. J., Simpson, A., & Potts, T. (2011). The development of visual short-term memory for multifeature items during middle childhood. *Journal of Experimental Child Psychology*, *108*, 802-809. doi: 10.1016/j.jecp.2010.11.006

Ritter, S., Barrett, D. G., Santoro, A., & Botvinick, M. M. (2017). Cognitive psychology for deep neural networks: a shape bias case study. *arXiv preprint arXiv:1706.08606*. Retrieved from https://arxiv.org/abs/1706.08606

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2004). Infant visual recognition memory. *Developmental Review*, *24*, 74-100. doi: 10.1016/j.dr.2003.09.004

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2009). A cognitive approach to the development of early language. *Child Development*, *80*, 134-150. doi: 10.1111/j.1467-8624.2008.01250.x

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2012). Implications of infant cognition for executive functions at age 11. *Psychological Science*, *23*, 1345-1355. doi: 10.1177/0956797612444902

Ross-Sheehy, S., & Eschman, B. (2019). Assessing visual stm in infants and adults: Eye movements and pupil dynamics reflect memory maintenance. *Visual Cognition*, *27*(1), 78-92.

Ross-Sheehy, S., Oakes, L. M., & Luck, S. J. (2003). The development of visual short-term memory capacity in infants. *Child Development*, *74*(6), 1807–1822. doi: 10.1046/j.1467-8624.2003.00639.x

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science*, *274*(5294), 1926-1928.

Saffran, J. R., Hauser, M., Seibel, R., Kapfhamer, J., Tsao, F.-M., & Cushman, F. (2008). Grammatical pattern learning by human infants and cotton-top tamarin monkeys. *Cognition*, *107*(2), 479–500. doi: 10.1016/j.cognition.2007.10.010

Saffran, J. R., & Kirkham, N. Z. (2018). Infant statistical learning. *Annual Review of Psychology*, *69*, 181-203. doi: 10.1146/annurev-psych-122216-011805

Saffran, J. R., & Thiessen, E. D. (2003). Pattern induction by infant language learners. *Developmental Psychology*, *39*(3), 484–494. doi: 10.1037/0012-1649.39.3.484

Salley, B., Panneton, R. K., & Colombo, J. (2013). Separable attentional predictors of language outcome. *Infancy*, *18*, 462-489. doi: 10.1111/j.1532-7078.2012.00138.x

Samuelson, L. K. (2002). Statistical regularities in vocabulary guide language acquisition in connectionist models and 15-20-month-olds. *Developmental psychology*, *38*, 1016-1037. doi: 10.1037/0012-1649.38.6.1016

Samuelson, L. K. (2021). Toward a precision science of word learning: Understanding individual vocabulary pathways. *Child Development Perspec-*

tives, *15*, 117-124. doi: 10.1111/cdep.12408

Samuelson, L. K., & Horst, J. S. (2007). Dynamic noun generalization: Moment-to-moment interactions shape children's naming biases. *Infancy*, *11*, 97-110. doi: 10.1207/s15327078in1101_5

Samuelson, L. K., & Horst, J. S. (2008). Shape bias special section: Confronting complexity: Insights from the details of behavior over multiple timescales. *Developmental Science*, *11*, 209-215. doi: 10.1111/j.1467-7687.2007.00667.x

Samuelson, L. K., & McMurray, B. (2017). What does it take to learn a word? *Wiley Interdisciplinary Reviews: Cognitive Science*, *8*. doi: 10.1002/wcs.1421

Samuelson, L. K., & Smith, L. B. (1999). Early noun vocabularies: Do ontology, category structure and syntax correspond? *Cognition*, *73*, 1-33. doi: 10.1016/S0010-0277(99)00034-7

Samuelson, L. K., & Smith, L. B. (2000). Children's attention to rigid and deformable shape in naming and non-naming tasks. *Child Development*, *71*, 1555-1570. doi: 10.1111/1467-8624.00248

Sandhofer, C. M., & Smith, L. B. (1999). Learning color words involves learning a system of mappings. *Developmental Psychology*, *35*(3), 668–679.

Schurgin, M. W. (2018). Visual memory, the long and the short of it: A review of visual working memory and long-term memory. *Attention, Perception, and Psychophysics*, *80*, 1035-1056. doi: 10.3758/s13414-018-1522-y

Schwab, J. F., & Lew-Williams, C. (2016). Language learning, socioeconomic status, and child-directed speech. *Wiley Interdisciplinary Reviews: Cognitive Science*, *7*, 264-275. doi: 10.1002/wcs.1393

Shinskey, J. L., & Munakata, Y. (2010). Something old, something new: a developmental transition from familiarity to novelty preferences with hidden objects. *Developmental Science*, *13*(2), 378-384. doi: 10.1111/j.1467-7687.2009.00899.x

Shipley, K. G., & McAfee, J. G. (2015). *Assessment in speech-language pathology: A resource manual* (5th ed.). Boston: Cengage Learning.

Sia, M. Y., Holmboe, K., & Mani, N. (2023). The relation between attention, inhibition and word learning in young children. *Collabra: Psychology*, *9*. doi: 10.1525/collabra.90755

Simcock, G., & Hayne, H. (2003). Age-related changes in verbal and nonverbal memory during early childhood. *Developmental Psychology*, *39*(5), 805–814. doi: 10.1037/0012-1649.39.5.805

Simion, F., Regolin, L., & Bulf, H. (2008). A predisposition for biological motion in the newborn baby. *Proceedings of the National Academy of Sciences*, *105*(2), 809–813. doi: 10.1073/pnas.0707021105

Simmering, V. R. (2012). The development of visual working memory capacity during early childhood. *Journal of Experimental Child Psychology*, *111*, 695-707. doi: 10.1016/j.jecp.2011.10.007

Simmering, V. R. (2016). Working memory capacity in context: Modeling dynamic processes of behavior, memory, and development. *Monographs of the Society for Research in Child Development*, *81*(3), 7–24. doi: 10.1111/mono.12249

Sims, C. E., Schilling, S. M., & Colunga, E. (2013). Exploring the developmental feedback loop: Word learning in neural networks and toddlers. In *Proceedings of the annual meeting of the cognitive science society* (Vol. 35, pp. 3408–3413). Retrieved from `https://escholarship.org/uc/item/5c25q4k2`

Singleton, N. C. (2018). Late talkers: Why the wait-and-see approach is outdated. *Pediatric Clinics*, *65*(1), 13-29. doi: 10.1016/j.pcl.2017.08.018

Slone, L. K., Smith, L. B., & Yu, C. (2019). Self-generated variability in object images predicts vocabulary growth. *Developmental Science*, *22*(6), e12816.

Sluzenski, J., Newcombe, N. S., & Kovacs, S. L. (2006). Binding, relational memory, and recall of naturalistic events: A developmental perspective. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*(1), 89–100. doi: 10.1037/0278-7393.32.1.89

Smith, L. B. (2001). How domain-general processes may create domain- specific biases. *Cambridge university press*.

Smith, L. B. (2003). Learning to recognize objects. *Psychological Science*, *14*(3), 244-250.

Smith, L. B. (2009). From fragments to geometric shape: Changes in visual object recognition between 18 and 24 months. *Current Directions in Psychological Science*, *18*(5), 290–294. doi: 10.1111/j.1467-8721.2009.01654.x

Smith, L. B., & Gasser, M. (2005). The development of embodied cognition: Six lessons from babies. *Artificial Life*, *11*(1-2), 13–29.

Smith, L. B., Jones, S. S., Landau, B., Gershkoff-Stowe, L., & Samuelson, L. (2002). Object name learning provides on-the-job training for attention. *Psychological Science*, *13*, 13-19. doi: 10.1111/1467-9280.00403

Smith, L. B., & Slone, L. K. (2017). A developmental approach to machine learning? *Frontiers in Psychology*, *8*. doi: 10.3389/fpsyg.2017.02124

Smith, L. B., & Yu, C. (2008). Infants rapidly learn word-referent mappings via cross-situational statistics. *Cognition*. doi: 10.1016/j.cognition.2007.06.010

Smolak, E., McGregor, K. K., Arbisi-Kelm, T., & Eden, N. (2020). Sustained attention in developmental language disorder and its relation to working memory and language. *Journal of Speech, Language, and Hearing Research*, *63*, 4096-4108. doi: 10.1044/2020_JSLHR-20-00265

Snowling, M. J., Duff, F. J., Nash, H. M., & Hulme, C. (2016). Language profiles and literacy outcomes of children with resolving, emerging, or persisting language impairments. *Journal of Child Psychology and Psychiatry*, *57*(12), 1360-1369.

Spencer, J. P. (2020). The development of working memory. *Current Directions in Psychological Science*, *29*, 545-553. doi: 10.1177/0963721420959835

Spencer, J. P., Forbes, S. H., Naylor, S., Singh, V. P., Jackson, K., Deoni, S., ... Kumar, A. (2023). Poor air quality is associated with impaired visual cognition in the first two years of life: A longitudinal investigation. *eLife*, *12*. doi: 10.7554/eLife.83876

Sung, F., Yang, Y., Zhang, L., Torr, P. H., & Hospedales, T. M. (2018). Learning to compare: Relation network for few-shot learning. In *Proceedings of the ieee conference on computer vision and pattern recognition (cvpr)* (pp. 1199–1208).

Swingley, D. (2010). Fast mapping and slow mapping in children's word learning. *Language Learning and Development*, *6*, 179-183. doi: 10.1080/15475441.2010.484412

Tek, S., Jaffery, G., Fein, D., & Naigles, L. R. (2008). Do children with autism spectrum disorders show a shape bias in word learning? *Autism Research: Official Journal of the International Society for Autism Research*, *1*(4), 208–222. doi: 10.1002/aur.38

Thal, D. J., Bates, E., Goodman, J., & Jahn-Samilo, J. (1997). Continuity of language abilities: An exploratory study of late- and early-talking toddlers. *Developmental Neuropsychology*, *13*, 239-273. doi: 10.1080/87565649709540681

Tomasello, M. (1988). The role of joint attentional processes in early language development. *Language Sciences*, *10*(1), 69-88.

Trueswell, J. C., Medina, T. N., Hafri, A., & Gleitman, L. R. (2013). Propose but verify: Fast mapping meets cross-situational word learning. *Cognitive Psychology*, *66*, 126-156. doi: 10.1016/j.cogpsych.2012.10.001

Truong, J., Buschkuehl, M., Smith-Peirce, R. N., Carrillo, A. A., Seitz, A. R., & Jaeggi, S. M. (2022). Change-detection training and its effects on visual processing skills. *Scientific Reports*, *12*. doi: 10.1038/s41598-022-15649-x

Vales, C., & Smith, L. B. (2015). Words, shape, visual search and visual working memory in 3-year-old children. *Developmental Science*, *18*(1), 65-79.

Vales, C., & Smith, L. B. (2018). When a word is worth more than a picture: Words lower the threshold for object identification in 3-year-old children. *Journal of Experimental Child Psychology*, *175*, 37–47. doi: 10.1016/j.jecp.2018.04.015

Visser-Bochane, M. I., Reijneveld, S. A., Krijnen, W. P., van der Schans, C. P., & Luinge, M. R. (2020). Identifying milestones in language development for young children ages 1 to 6 years. *Academic Pediatrics*, *20*, 421-429. doi: 10.1016/j.acap.2019.07.003

Vissers, C. T., Koolen, S., Hermans, D., Scheper, A., & Knoors, H. (2015). Executive functioning in preschoolers with specific language impairment. *Frontiers in Psychology*, *6*. doi: 10.3389/fpsyg.2015.01574

Vlach, H. A. (2016). How we categorize objects is related to how we remember them: The shape bias as a memory bias. *Journal of Experimental Child Psychology*, *152*, 12-30. doi: 10.1016/j.jecp.2016.06.013

Vlach, H. A., & DeBrock, C. A. (2017). Remember dax? relations between children's cross-situational word learning, memory, and language abilities. *Journal of Memory and Language*, *93*, 217-230. doi: 10.1016/

j.jml.2016.10.001

Vlach, H. A., & DeBrock, C. J. (2019). Prior knowledge influences on toddlers' cross-situational word learning. *Journal of Experimental Child Psychology, 178*, 17-33.

Vlach, H. A., & Johnson, S. P. (2013). Memory constraints on infants' cross-situational statistical learning. *Cognition*, *127*(3), 375-382.

Vlach, H. A., & Sandhofer, C. M. (2012). Distributing learning across objects and time: Benefits to language learning. *Journal of Experimental Child Psychology*, *112*(4), 543-561. doi: 10.1016/j.jecp.2012.03.006

Vogel, E. K., Woodman, G. F., & Luck, S. J. (2001). Storage of features, conjunctions and objects in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(1), 92–114. doi: 10.1037//0096-1523.27.1.92

Vukovic, R. K., & Lesaux, N. K. (2013). The language of mathematics: Investigating the ways language counts for children's mathematical development. *Journal of Experimental Child Psychology*, *115*, 227-244. doi: 10.1016/j.jecp.2013.02.002

Weill, F. (2011). *The role of verbal working memory in new word learning in toddlers 24 to 30 months old.* Retrieved from https://scholarship.shu.edu/dissertations/1769

Werker, J. F., Cohen, L. B., Lloyd, V. L., Casasola, M., & Stager, C. L. (1998). Acquisition of word-object associations by 14-month-old infants. *Developmental Psychology*, *34*, 1289-1309.

West, K. L., & Iverson, J. M. (2017). Object manipulation and environmental exploration in infancy: Links to sensorimotor and cognitive development. *Current Directions in Psychological Science*, *26*(2), 145-151. doi: 10.1177/0963721416672644

Wiguna, T., Mh, M. I., Wr, N. S., Kaligis, F., & Belfer, M. L. (2012). Learning difficulties and working memory deficits among primary school students in jakarta, indonesia. *Clinical Psychopharmacology and Neuroscience*, *10*, 105.

Wijeakumar, S., & Spencer, J. (2020). A dynamic field theory of visual working memory. In (p. 358-388). Oxford University Press. doi: 10.1093/oso/9780198842286.003.0013

Wilson, J., Andrews, G., Hogan, C., Wang, S., & Shum, D. H. K. (2018). Executive function in middle childhood and the relationship with theory of mind. *Developmental Neuropsychology*, *43*(3), 163–182. doi: 10.1080/87565641.2018.1440296

Wojcik, E. H. (2013). Remembering new words: Integrating early memory development into word learning. *Frontiers in Psychology*, *4*, 45287.

Wojcik, E. H. (2017). 2.5-year-olds' retention and generalization of novel words across short and long delays. *Language Learning and Development*, *13*, 300-316. doi: 10.1080/15475441.2016.1275644

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, *69*(1), 1–34. doi: 10.1016/s0010-0277(98)00058-4

Yee, M., Jones, S. S., & Smith, L. B. (2012). Changes in visual object recognition precede the shape bias in early noun learning. *Frontiers in Psychology*, *3*, 1-13. doi: 10.3389/fpsyg.2012.00533

Yoo, J., & Yim, D. (2018). Relationship among executive functions, vocabulary and reading skills in school-aged children with and without poor vocabulary. *Communication Sciences & Disorders*, *23*(3), 570–583. doi: 10.12963/csd.18523

Yoshida, H., & Fausey, C. (2018). Visual objects encountered by young language learners. In G. Westermann & N. Mani (Eds.), *Active vision* *and perception in language acquisition* (pp. 105–120). Routledge. doi: 10.4324/9781315110622-7

Yu, C., & Smith, L. B. (2012). Embodied attention and word learning by toddlers. *Cognition*, *125*, 244-262. doi: 10.1016/j.cognition.2012.06.016

Yu, C., & Smith, L. B. (2016). The social origins of sustained attention in one-year-old human infants. *Current Biology (CB)*, *26*(9), 1235–1240. doi: 10.1016/j.cub.2016.03.026

Yu, C., Suanda, S. H., & Smith, L. B. (2019). Infant sustained attention but not joint attention to objects at 9 months predicts vocabulary at 12 and 15 months. *Developmental Science*, *22*. doi: 10.1111/desc.12735

Yurovsky, D., Bion, R. A. H., Smith, L. B., & Fernald, A. (2012). Mutual exclusivity and vocabulary structure. *Proceedings of the 34th Annual Conference of the Cognitive Science Society*, 1208–1214.