Georg-August-Universität Göttingen

Bagger or *Bär*? The influence of individual interests on early word learning

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DISSERTATION

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"[Children] continously suggest to us what interests them, and what they would like to explore in a deeper way."

Loris Malaguzzi

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Abstract

Young children are remarkable word learners: At the end of the first year of life, typically developing children only produce a handful of words, but their vocabularies grow many times over during the second and third year of life. While the overall pattern of vocabulary growth is relatively stable across children and languages, we observe considerable variability with regard to the individual words known to children. Historically, this variability has been explained in terms of differences in the quantity and quality of input that children receive. Recently renewed interest in the child as an active learner provides a promising backdrop against which this thesis aims to examine variability in the early lexicon: Children strucuture their own learning environment by preferentially attending to and learning from stimuli that interest them. Across three eye-tracking studies, this dissertation investigates the influence of interest on early word learning and vocabulary composition in children aged two to three years. Interest was measured using pupillometry and parental reports. The first study examined whether interest in a novel object and in the semantic category to which the object belongs helps 30-month-old children form new word-object associations. We found that children more robustly recognized word-object associations from high-interest categories. This result points at a key role of the child and their interests in early word learning. Building on these findings, the second study examined the role of interest in novel word retention. Children aged 24 and 38 months were tested on their recognition of newly-learnt word-object associations immediately after exposure and with delays of five minutes and 24 hours. We found evidence for a beneficial role of category interest especially at 24 months, an age group for which previous evidence of word retention in laboratory word learning tasks was limited. In the third study, we tested whether interest guides 30-to-36-month-old children's referent assignment in a referentially ambiguous word learning situation. Here, we found that referent assignment was guided by relative interest in one object over the other, while there was no evidence for a role of category-level interest in resolving referential ambiguity. Taken together, the results of all three studies point at a vital role of interest in early word learning: Referent selection, initial word-object mappings, and longer-term word retention are all positively influenced by interest

at the object or category level. This thesis adds to our growing understanding of the importance of interest in early learning and development.

Abstract

Kleinkinder verfügen über ein beeindruckendes Vermögen, neue Wörter zu lernen: Am Ende des ersten Lebensjahrs produzieren Kinder mit einer typischen Entwicklung lediglich eine Handvoll Wörter, aber ihr Wortschatz wächst im zweiten und dritten Lebensjahr um ein Vielfaches. Der allgemeine Verlauf der Wortschatzentwicklung ist über verschiedene Kinder und Sprachen hinweg stabil, allerdings beobachten wir beachtliche Unterschiede im Hinblick auf die individuellen Wörter, die einzelne Kinder kennen. In der Vergangenheit wurde diese Variabilität hauptsächlich durch Unterschiede in der Quantität und Qualität des Inputs erklärt, dem Kinder ausgesetzt sind. Aktuell wiedererstarktes Interesse am Kind als aktive*r Lerner*in bietet einen Hintergrund, vor dem diese Dissertation Variabilität im frühkindlichen Wortschatz untersucht: Kinder strukturieren ihre Lernumgebung, indem sie ihre Aufmerksamkeit präferiert auf für sie interessante Stimuli lenken und von diesen lernen. Anhand von drei Eyetracking-Studien untersucht diese Dissertation die Rolle des Interesses auf Wortlernen und Wortschatz bei Kindern im Alter von zwei bis drei Jahren. Interesse wurde mithilfe von Pupillometrie und Elternfragebögen gemessen. Die erste Studie untersucht, ob Interesse an einem Objekt oder an der Kategorie, zu dem das Objekt gehört, 30 Monate alten Kindern dabei hilft, neue Wort-Objekt-Assoziationen zu lernen. Wir fanden heraus, dass Kinder Wörter aus Kategorien, für die sie sich stärker interessieren, besser wiedererkennen. Dieses Ergebnis suggeriert eine zentrale Rolle des Kindes und seiner Interessen im Wortlernen. Auf diese Ergebnisse aufbauend untersucht die zweite Studie die Rolle von Interesse bei der Retention neuer Wörter. Das Worterkennen wurde bei Kindern im Alter von 24 und 38 Monaten direkt nach der Exposition sowie mit Verzögerungen von fünf Minuten und 24 Stunden getestet. Eine förderliche Rolle des Interesses wurde insbesondere bei den 24 Monate alten Kindern gefunden, einer Gruppe, für die es bisher nur begrenzte Evidenz für erfolgreiche Retention in Wortlernstudien gab. In der dritten Studie wurde untersucht, ob Interesse die Referentenauswahl in einer referentiell ambigen Wortlernsituation bei Kindern zwischen 30 und 36 Monaten beeinflusst. Wir fanden heraus, dass die Zuweisung des Worts zu einem Referenten vom relativen

Interesse für einen der beiden möglichen Referenten im Vergleich zum anderen beeinflusst wurde, während es keine Evidenz für eine Rolle des Kategorieninteresses bei der Auflösung referentieller Ambiguität gab. Zusammengenommen suggerieren die Ergebnisse aller drei Studie eine zentrale Rolle von Interesse in Wortlernenprozessen auf verschiedenen Zeitskalen: Referentenauswahl, die initiale Bildung einer Wort-Objekt-Assoziation und längerfristige Retention werden alle positiv von Interesse auf dem Objekt- oder Kategorienlevel beeinflusst. Diese Disseration liefer einen Beitrag zu unserem wachsenden Verständnis von der Rolle des Interesses in frühen Lern- und Entwicklungsprozessen.

Contents

Chapter 1

Introduction

"The problem of learning words is a problem of ambiguity, wrapped in uncertainty and shrouded in vagueness." (Horst, Samuelson, Kucker, & McMurray, 2011, p. 234)

1.1 Aims and scope

Children are born into a world of words and things. From an adult perspective, it seems obvious that a connection exists between the two: Every day, we use thousands of words to refer not only to the things in our environment, but also to abstract, absent or hypothetical entities. We take language and its referential properties for granted, but there is one word that we consider particularly remarkable – a child's first word, typically produced around the first birthday. Most caregivers are able to recall when their child uttered their first word and what it was.

Vocabulary growth is slow at first, allowing caregivers to keep track of new words their children learn for a while, but speeds up during the second year of life. As children add more words to their vocabularies, we can observe considerable differences not only in the size of the lexicon, but also with regard to the words and categories that individual children know: Some children can name every animal they encounter at the zoo, while others will correctly label every vehicle they see at a construction site.

This thesis aims to shed new light on variability in the early lexicon at two to three years of age. At this point, typically developing children have long passed the milestone of their first word and have added hundreds of words to their lexicon. While these individual differences in early vocabularies have historically mostly been explained in terms of input, this thesis focuses on another potential source of variability: The child and their interest in objects and categories in the learning environment. Recent approaches to learning and development see the child as a curious learner who actively explores their surroundings and shapes their learning environment. Following this approach of curiosity-driven learning, this thesis will explore how children's interest in objects and categories drives their word learning and shapes the composition of their vocabularies.

Across three eye tracking studies, the influence of object interest and category interest will be explored in different word learning situations: The first study examines novel word recognition immediately after exposure to a novel object, the second study tests children's retention of newly acquired word-object-associations, and the third study explores to what extent interest helps children resolve ambiguous word learning situations.

These three studies are the first to empirically test the strikingly intuitive hypothesis that children's word learning is driven not only by their interest in a novel object itself, but also by their interest in the superordinate category the object belongs to. In addition to examining the relationship between object interest, category interest and word learning, this thesis also sets out to explore how the elusive psychological concept of interest can be quantified using pupillometry and parental report measures.

1.2 Early word learning

One of the aspects that caregivers find most remarkable about early language development is the speed at which children learn new words. Some parents keep journals to which they add every new word their child says, up until the point where they can no longer keep up with their child's rapid vocabulary growth. While parents are amazed at the growth rate of children's expanding vocabularies, the underlying mechanisms that allow children to acquire rich vocabularies in such a short time have been a topic of research and debate for decades (cf. P. Bloom, 2000; Samuelson & McMurray, 2017a; Tomasello, 2000, 2003; Westermann & Mani, 2017).

At the age of 24 months – the youngest age group tested in the studies presented in this thesis – monolingual German-learning children have an average productive vocabulary of 223 words (according to FRAKIS data, cf. Szagun, Stumper, & Schramm, 2009). Learning 223 individual words might seem like a relatively straightforward task from an adult perspective: All that the child has to do, it could be argued, is to learn which word maps onto which object in the environment. However, this rather simplistic view of word learning overlooks the numerous linguistic and developmental accomplishments that precede the successful production of words: Word learning in the narrow sense of mapping words onto referents is not an isolated skill that suddenly emerges at the end of the first year of life. Before children start producing their first words, they first have to master several other steps on their way to becoming proficient users of their native language(s). What follows is an overview of the "overlapping and interacting processes" (Westermann & Mani, 2017, p. 3) in early development that pave the way for the successful acquisition of hundreds of words by just two years of age.

1.2.1 Before the first word - Sounds and segmentation

Children start out with well-developed speech perception abilities, but very limited speech production capabilities (Benders & Altvater-Mackensen, 2017). Born as "universal listeners", able to discriminate sound contrasts in all languages (Werker & Tees, 1984), they lose this ability over the course of the first year of life as their speech perception zeroes in on the phoneme inventory and sound contrasts of language they are acquiring, a developmental process also referred to as perceptual attunement (Kuhl, 1994; Kuhl et al., 2008). In addition to acquiring a phoneme inventory, children also have to learn how to segment the continuous speech stream into meaningful units (Junge, 2017), an ability that can first be observed around five months of age (Bortfeld, Morganm, Golinkoff, & Rathbun, 2005) and further develops across the second half of the first year (Jusczyk & Aslin, 1995; Schreiner, 2017). Indeed, both the acquisition of a native phoneme inventory and speech segmentation abilities have been linked to later language acquisition in general and the development of the early lexicon in particular (e.g. Werker & Curtin, 2005), highlighting the importance of these early accomplishments to what is commonly referred to as word learning.

This developmental continuity from early sound perception to later word learning suggests that word learning entails more than simply mapping words to objects (see also Westermann & Mani, 2017).

1.2.2 Mapping and reference

The next step towards word learning is assigning meaning to the units segmented from the speech stream, i.e. mapping words onto objects in the environment. The observation that a meaningful connection exists between words and objects is trivial to adults: In a room full of different objects, an adult will select the correct one when asked to "grab the chair". However, this everyday interaction is only possible because the listener has not only identified the individual words in the utterance but also linked the word chair to the exemplar of the category CHAIR that it refers to in the given context.

To successfully learn words, children therefore have to discover that words refer to objects: Words do not merely coincide or "go with" objects in the environment, but they stand for their referent, even if the referent is not present when the label is uttered (Hollich, Hirsh-Pasek, & Golinkoff, 2000; Waxman & Gelman, 2009). When and how children arrive at this conclusion has been a topic of debate for decades. Eventually, all answers that have been proposed to the puzzle of word learning over the years link back to a longstanding theoretical debate about the fundamental nature of language acquisition: What is it that allows children to acquire a system as complex as human language in a relatively short time and with seemingly very little effort?

Frank, Braginsky, Yurovsky, and Marchman (2020) identify two axes along which answers to this question can be categorized: On the first axis, they distinguish nativist from empiricist approaches, while the other axis concerns the distinction between domain-general and domain-specific learning mechanisms that lie at the heart of young children's language acquisition. Frank et al. (2020) note that the field of language acquisition has become polarized along an implied "axis of debate" with nativist approaches that favour domain-specific explanations on one end, and empiricist approaches proposing domain-general learning mechanisms at the other. This claim echoes a similar observation, made 20 years earlier, that "theories of word learning have been polarized by emphasizing a single word learning strategy" (Hollich et al., 2000, p. 2).

Nativist or constraint-based (Hollich et al., 2000) approaches to word learning can be traced back to Chomsky (1965) who proposes that children come into the world equipped with domain-specific learning mechanisms that allow for the rapid acquisition of syntactic structure. According to Chomsky, this innate linguistic knowledge is tied to what he calls the poverty of the stimulus: Data from the input that children are exposed to is not sufficient to acquire the complete grammatical structure of their native language. Given that children do eventually acquire a complete grammar, they must possess some innate linguistic capacities (Chomsky, 1965, 1980; Lasnik & Lidz, 2016). These approaches assume the existence of a priori constraints or principles that are specific to language. Markman (Markman, 1990; Markman & Wachtel, 1988) argues for such innate constraints that help children map words onto objects, the implications of which are discussed below. Furthermore, early nativist accounts argued that children come equipped with an innate concept of reference (Macnamara, 1972, 1982).

Smith (1999; 2000) identifies associative learning as the driving mechanism behind children's rapid vocabulary growth in the first years of life: Associative learning mechanisms – which are not language-specific, but have been observed to guide learning across various domains (cf. Shanks, 1995) – allow children to develop a shape bias. This shape bias (cf. also Kucker et al., 2019; Landau, Smith, & Jones, 1988), emerging from slow associative learning of word-object-mappings, then speeds up subsequent vocabulary learning. Smith's (1999; 2000) account of the shape bias thus presents a case in which a domain-general process breeds a domain-specific one, highlighting the complexity and nuance of the theoretical debate.

Another domain-general mechanism that the empiricist approach gives special attention to is statistical learning, an ability that children make use of in a range of tasks, including speech segmentation, non-adjacent dependency learning and word learning (Creel, Newport, & Aslin, 2004; Saffran, Aslin, & Newport, 1996; L. Smith & Yu, 2008). In an empiricist view, children do not need to possess a concept of reference but discover the referential properties of language through associative learning, eliminating the need for a sudden "naming insight" (Kamhi, 1986).

The social-pragmatic theory of word learning, first proposed under this name by (Tomasello, 2000) but drawing on earlier works by Bruner (1983) and Tomasello himself (Tomasello, 1992; Tomasello & Barton, 1994), conceptualizes word learning as cultural learning and emphasizes its social component. According to this view, children map words onto objects by taking into account adults' referential intentions – word learning is thus guided not by language-specific constraints, but by the pragmatics of a given word learning situation. Reference is thus neither an innate concept nor learnt through association, but is created in interaction through the use of social-pragmatic cues.

In a nativist framework, children are seemingly effortless word learners thanks to innate abilities that set them up specifically for word learning. Empiricist accounts, on the other hand, see children as domain-general learners, becoming expert word learners by flexibly employing and combining learning mechanisms. Socio-pragmatic views do not disavow that domain-general mechanisms play an important role, but highlight the importance of social context and pragmatics. These distinctions are especially relevant with regard to one of the central challenges of word learning, namely the problem of referential ambiguity.

1.2.3 Referential Ambiguity

Word learning – while often reduced to unambiguous one-to-one mappings in laboratory tasks (cf. Horst et al., 2011)– occurs in situations in which children must parse cluttered visual scenes and auditory input simultaneously to successfully determine the correct referent of a word. The core problem of referential ambiguity is illustrated in Quine's (1960) Gavagai example: A linguist undertaking field work hears a native speaker utter the sounds sequence gavagai as a rabbit hops by. The meaning of this utterance, however, is underdetermined in this situation. How does the linguist find out whether gavagai refers to the rabbit, the action of hopping, or any of the rabbit's attributes? Children find themselves undertaking this kind of "field work" every day as they encounter new words and objects in their surroundings. Their success at this difficult feat – acquiring hundreds of words between their first and second birthday and thousands more before starting school (Carey, 1978) – has been a topic of debate for over 30 years (Clerkin, Hart, Rehg, Yu, & Smith, 2017; Samuelson & McMurray, 2017a).

Potential explanations to how children resolve the Quinean problem can be linked back to the theoretical debate and its axes outlined above. Approaches in the nativist tradition propose certain innate biases and constraints specific to the domain of language that guide children towards the correct mapping between words and referents in ambiguous situation. One such constraint is the mutual exclusivity (ME) bias, first proposed by Markman and Wachtel (1988): Children will reject a second label for an already-named object and instead assign the label to a novel object. While Markman and Wachtel (1988) tie this observed behavior back to an innate constraint, it has since then examined in detail across different age groups and from different theoretical backgrounds. Across the literature, different underlying cognitive processes and mechanisms have been proposed to explain children's rejection of a novel label for a known object: Diesendruck and Markson (2001) propose a socio-pragmatic account that conceptualizes children's avoidance of lexical overlap as a result of their sensitivity to communicative intentions rather than an a priori bias. Halberda (2003) found that 14-months-olds do not yet show a mutual exclusivity bias, challenging the idea of its innateness. According to Halberda (2006), referentially ambiguous situations are resolved by employing disjunctive syllogism ("A or B, not A, therefore B", i.e. rejecti ng the known distractor before assigning the label to the novel object), a line of reasoning that is consistent with both constraint-based and socio-pragmatic theories. Furthermore, Mather and Plunkett (2009, 2010, 2012) highlight the influence of factors such as stimulus repetition and phonological novelty on children's usage of mutual exclusivity.

Other domain-specific constraints that have been proposed are the shape bias (Landau et al., 1988 , but see L. Smith, 1999, 2000, for the argument that this language-specific bias emerges from domain-general processes) and the whole-object constraint (Markman, 1990). Additionally, the socio-pragmatic camp proposes solutions to referential ambiguity that rely on children taking into account social information such as eyegaze (Baldwin, 1993), the experimenter's familiarity with the objects (Akhtar, Carpenter, & Tomasello, 1996), and the experimenter's excitement

(MacPherson & Moore, 2010; Tomasello, 2003): In an ambiguous word learning situation, the child will attend to and use pragmatic cues to infer the speaker's intention and constrain possible word-object-mappings accordingly.

More recently, the constraint-based and socio-pragmatics views on word learning outlined above have been complemented by explanations favouring domain-general approaches, consistent with empiricist theories of early language and cognitive development. While evidence for domain-specific, potentially innate constraints mainly comes from simple referent selection tasks (cf. Kucker, McMurray, & Samuelson, 2020, , see below), recent advances in our understanding of early development reframe or constrain the problem of referential ambiguity (Samuelson & McMurray, 2017a). Studies with head-mounted cameras (Clerkin et al., 2017; Yoshida & Smith, 2008), for example, offer new insight into the visual environment of young children and its relation to word learning: Not only do children typically have fewer objects in their field of view than adults, these objects also follow a highly skewed frequency distribution: Children are exposed to significantly more tokens of high-frequency objects, resulting in visual environments that are markedly different from those used in traditional word-learning studies. This skewed structure of the visual environment that favours high-frequency objects reduces the amount of referential ambiguity in the Quinean sense. Additionally, the frequency distribution changes as the child develops (L. Smith, Jayaraman, Clerkin, & Yu, 2018; Yu & Smith, 2012b), thereby highlighting different word-object-pairs at different timepoints. As the structure of the visual environment itself constrains the hypothesis space, the need for highly specific learning mechanisms is eliminated. Instead, proponents of this view favour domain-general mechanisms including attention (Kidd, Piantadosi, & Aslin, 2012, 2014), memory (Vlach & Sandhofer, 2012), a novelty bias (Horst et al., 2011), and statistical learning mechanisms (Yu & Smith, 2007).

These more recent insights into the statistics of children's visual environments force us to revisit earlier accounts of word learning and referential ambiguity: Constraint-based theories that posit the existence of highly specialized learning mechanisms might have overestimated the magnitude of the problem of referential ambiguity in everyday word learning situations. But even in light of more recent findings, the challenge of determining correct mappings between words and objects remains. Combined evidence from the numerous studies outlined above suggests that children do not rely on a single word-learning mechanism but make use of several strategies – both domain-specific and domain-general – that guide them as they undertake Quine's "field work".

1.2.4 Word learning at different timescales

These strategies help children build impressive vocabularies in a relatively short period of time: Between 18 and 24 months of age, German-learning children increase their productive lexicon from an average of 17 to an average of 223 words (Szagun et al., 2009). The growth rate is sometimes expressed as "words per day" that a child adds to their vocabulary, giving the impression that learning a new word is a singular event that takes places at a definable point in time. Indeed, children start forming a link between a word and its referent upon their first encounter with a novel word, as evidenced by their successful performance in referent selection tasks (e.g. Carey & Bartlett, 1978). In its simplest form, a referent selection task presents children with a novel object and known distractors and prompts them to pick an object labelled with a novel word. Using their disambiguation skills, children aged 2 years and older will reliably choose the novel object (Bion, Borovsky, & Fernald, 2013; Kucker et al., 2020) in this task. This ability to quickly form a first association between words and referents has also been called fast mapping. Referent selection tasks, however, do not give us any indication of children's word retention, i.e. whether the word-object-association can be recalled after a delay.

Indeed, recent research suggests that successful referent selection or fast mapping is distinct from long-term learning (Bion et al., 2013; Horst & Samuelson, 2008): Bion et al. (2013) show that children reliably fast map at 24 months, but do not show retention until 30 months of age in a laboratory word learning task, suggesting that children at 24 months do not learn from a single exposure. Similarly, Horst and Samuelson (2008) only find evidence of retention in 24-month-olds when the target object's salience was increased. These findings give rise to the question what counts as successful word learning. Horst (2017) proposes two ways to identify whether a child has successfully learnt a word, namely testing their generalization (i.e. the extension of the word meaning to new exemplars of the same category, e.g. Axelsson, Williams, & Horst, 2016) and retention abilities. Testing word retention in addition to referent selection highlights one of the core aspects of word learning: Word learning is a process that operates on multiple timescales.

While children show remarkable abilities to identify the referent of a novel word in real time early on, adding individual words to the growing lexicon is a slow process (Bion et al., 2013; Kucker, Mcmurray, & Samuelson, 2015). To successfully learn a word, children have to build up and strengthen the correct mapping between a word and its referent across multiple occurrences, while simultaneously pruning any incorrect associations they might have formed initially (Kucker et al., 2015; McMurray, Horst, & Samuelson, 2012). Thus, word learning operates at two timescales, namely situation time and developmental time (after Kucker et al., 2015; McMurray, 2016). The processes that underlie referent selection in situation time and learning in developmental time are interrelated, but should not be conflated, as insights from studies examining disambiguation and retention as outlined above show. Testing retention thus sheds further light on the mechanisms that operate on longer time scales and determine whether a fleeting first association eventually enters the child's lexicon and becomes part of their vocabulary.

1.3 Structure of the early lexicon

1.3.1 Consistency

As outlined above, associating words and referents is a complex, multi-layered process that operates on different timescales and requires children to keep track of the co-occurrence of words and objects across time and space. Despite the difficulty of the task, most children eventually acquire new words with seemingly effortless ease: At the end of the first year of life, the productive vocabulary of a typically developing child comprises a handful of words. This number increases drastically over the second and third year of life, reaching an average of 316 words at 24 months of age and over 500 words just six months later for American English-learning children (Frank et al., 2020), determined by parental responses to the MacArthur-Bates Communicative Development Inventory (MBCDI, Fenson et al., 1994).

As the CDI has been adapted to more than 100 languages over the last decade (Frank et al., 2020), it is a valuable measure for comparing vocabulary development across languages and cultures. The Wordbank project applies a data-driven approach to questions of consistency in early word learning: Frank et al. (2020) compiled CDIs from various countries and languages to examine cross-linguistic patterns of early lexical development. Interestingly, early vocabulary trajectories are relatively stable cross-culturally and cross-linguistically: Examining data from 29 languages, Frank et al. (2020) found considerable overlap in the first-acquired words, echoing earlier findings from Schneider, Yurovsky, and Frank (2015) and Braginsky, Yurovsky, Marchman, and Frank (2019). These words typically refer to people (family members), objects (food items) and routines that play a role in children's everyday experiences regardless of cultural background. In contrast to the cross-linguistic similarity of those early-learnt words, words acquired at later stages of vocabulary development show greater variation across languages and might reflect cultural biases and practices (but see Tardif et al., 2008, for cross-linguistic differences even in early-acquired words). At the group level, the composition of the developing lexicon is heavily influenced by the cultural background. However, vocabulary growth rates and overall vocabulary size still follow similar patterns across languages.

Regardless of language, the growth patterns identified by Frank et al. (2020) confirm caregiver intuitions about language development: Most children start producing words around their first birthday. At the beginning, vocabulary growth is relatively small, but accelerates during the second year of life once their productive vocabulary has reached 50 to 100 words (Dapretto & Bjork, 2000). This switch from relatively slow to rapid growth is commonly described as a vocabulary spurt or vocabulary explosion in the literature (Dapretto & Bjork, 2000; Ganger & Brent, 2004), although it has been a subject of debate whether these terms accurately characterize the phenomenon of accelerated word learning (Dandurand & Shultz, 2011; McMurray, 2007).

1.3.2 Variability

While the overall trajectory of word learning is similar across children learning different languages, we also observe considerable variability with regards to vocabularies at an individual level, both in terms of quantity, i.e. vocabulary size, and quality, i.e. vocabulary composition. At 24 months of age, children acquiring American English are reported to have a mean productive vocabulary of 316 words, but individual productive vocabularies range in size from 0 to more than 600 of the 680 CDI items, with vocabulary size of 83 and 558 words representing the 10th and 90th percentile respectively (Frank, Braginsky, Yurovsky, & Marchman, 2017). Individual differences in vocabulary size have been identified early on as an important factor in language development with predicitve power for future language outcomes (e.g. Fenson et al., 1994; Huttenlocher, Haight, Bryk, & Seltzer, 1991).

Importantly, young children's vocabularies not only differ in the number of words, but also with regard to the individual words known to each child. During the period of accelerated vocabulary growth starting around 18 months of age, individual differences in vocabulary makeup are especially remarkable, at least in terms of CDI responses. Consider the developmental trajectories of the German words Bär and Bagger: At age 20 months, the average German-learning child produces 82 words from the CDI vocabulary list (Szagun et al., 2009). At that age, 52 % of children are reported to produce the word *Bagger* (digger) and 48 % of children are reported to produce the word *Bär* (bear), two words from two different early-acquired semantic categories, namely animals and vehicles. Interestingly, out of the children that produce at least one of the two words, 52 % of them produce one but not the other. At age 30 months, almost all German-learning children have added both words to their vocabularies. This word-level observation is corroborated on a larger scale by Mayor and Plunkett (2014) whose analysis of CDI data from nearly 15,000 children shows great individual variability in productive vocabularies between the ages of 18 and 24 months. As vocabularies reach a size of around 100 words, the makeup of individual expressive vocabularies starts to diverge, before converging again after the second birthday.

It should be noted that differences in vocabulary structure become harder to capture by instruments such as the CDI as children grow older and add even more words to their vocabularies (Borovsky & Elman, 2006): Eventually, most children will not only learn all of the words represented on the CDI, but also many more, making it more difficult to quantify variability at a later age. Between 20 and 30 months of age, the vocabulary of German-learning children grows to an average of 464 CDI items, representing an almost 6-fold increase in a 10-months period. As the findings of Mayor and Plunkett (2014) illustrate, this period of rapid vocabulary growth is characterized by individual differences in vocabulary structure, setting it apart from the stability observed with regard to earliest-acquired words (Frank et al., 2020). While the growth pattern remains relatively stable across children (Frank et al., 2020) not all children add new words to their lexicon in the same order. What factors explain why children learn the words they do?

1.3.3 Input and variability

Broadly speaking, influences on early word learning and lexical development can be broken down into two types, external and internal factors: Historically, differences in the early lexicon have mainly been explained in terms of external influences, i.e. the quality and the quantity of input that a child receives. More recent approaches place the child in a more active role and focus on the child as a source of variability and driving force of their language development.

Undeniably, children's language development is heavily influenced by what they see and hear. In the literature to date, the role of input has been examined in great detail with regard to different aspects of language development. Huttenlocher et al. (1991) and Hart and Risley (1995) were among the first to investigate the influence of the quantity of input, i.e. how many words a child hears, on vocabulary development as well as on later language outcomes and academic achievement. (Huttenlocher et al., 1991) are the first to identify the quantity of parental input as a significant predictor of vocabulary growth. In their seminal study, Hart and Risley (1995) found that children from lower socioeconomic backgrounds receive less language input than their peers from middle-class backgrounds across the first three years of life, resulting in what has come to be known as the 30 million word gap. This reduced exposure to linguistic input in early development has been linked to poorer cognitive and linguistic abilities at later ages as well as to reduced academic performance. Recent studies using LENA recording technologies provide mixed evidence for reduced input in children from lower socioeconomic backgrounds: While Sultana, Wong, and Purdy (2020) and Gilkerson et al. (2017) replicate the findings of Hart and Risley

(1995), Brushe, Lynch, Reilly, Melhuish, and Brinkman (2020) do not find variability in input quantity up to 12 months of age. The concept of an input deficit in relation to SES has also come under fire: Critics (e.g. Sperry, Sperry, & Miller, 2019) argue that the methodology used by Hart and Risley (1995) is flawed and that the relation between SES and language exposure is not as straightforward as initially assumed and that earlier studies confounded SES, race and education (Vernon-Feagans, Bratsch-Hines, Reynolds, & Willoughby, 2020), highlighting the complexity of the question. Bornstein, Haynes, and Painter (1998) propose a multivariate model that takes the complexity into account and posits an indirect influence of maternal SES on children's vocabulary outcomes. Similarly, Hoff (2003) finds that differences in maternal speech as a function of SES account for variation in vocabulary development.

At the same time, links between early language exposure and (later) linguistic abilities have also been identified with regard to the quality of the input. These approaches target a range of dimensions along wich the linguistic input that children receive differ, focussing on variability with regard to the length, complexity and diversity of utterances that children are exposed to, rather than exclusively looking at the quantity of words. Placing special emphasis on the role of interactions between infants and caregivers, this line of research has found that conversational and speech characteristics shape children's linguistics abilities and language outcomes. There is substantial evidence that diverse speech, including lexical diversity, the type of questions directed at the child and maternal responsiveness, accounts for variation in early vocabulary development and later language skills even within the same SES bracket (e.g. Bornstein, Tamis-LeMonda, & Haynes, 1999; Cristofaro & Tamis-LeMonda, 2012; Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; Huttenlocher, Vasilyeva, Waterfall, Vevea, & Hedges, 2007; Rowe, Coker, & Pan, 2004; Tamis-LeMonda & Bornstein, 1994; Tamis-LeMonda, Bornstein, & Baumwell, 2001; Tompkins, Meyer, & Justice, 2020; Vernon-Feagans et al., 2020). In a similar vein, Hirsh-Pasek et al. (2015) and Rowe (2008) found that indicators of input quality such as joint engagement and the fluency of communication not only vary greatly even within the same SES bracket, but also account for more variance in later language outcomes than the quantity of input alone. Additionally, the number of conversational turns in parent-child interactions - a measure that has been linked to parental

SES (Gilkerson et al., 2017) - impacts verbal skills (Romeo et al., 2018). Properties associated with infant-directed speech such as the repetition of words, the exposure to isolated words and higher mean pitch have also been shown to influence early language processing (McRoberts, McDonough, & Lakusta, 2009; Schreiner, 2017) and word learning (Brent & Siskind, 2001).

1.3.4 The child as a source of variability

The environment that a child grows up in and the resulting variation in the quality and quantity of input have been shown to impact children's word learning and overall language development. However, recent approaches also explore how factors related to the child contribute to the vast individual differences that we observe in early language development. While many characteristics along which young children differ, including gender (Fenson et al., 1994; Huttenlocher et al., 1991; Hyde, 1981), birth order (Fenson et al., 1994), and temperament (L. Bloom, 1993; Hilton & Westermann, 2017; Slomkowski, Nelson, Dunn, & Plomin, 1992), have been shown to influence their word learning trajectories – and overall language development – the following will focus on two dimensions and their influences on word learning: What a child knows and what a child is interested in.

While differences in input have some explanatory power with regard to variability in the lexicon, children are more than passive recipients of ideally-structured input provided by the caregiver. From infancy on, children actively explore their surroundings (Bonawitz, Bass, & Lapidow, 2018; Oudeyer & Smith, 2016) and impose structure on their learning environment by sampling information based on particular patterns that enhance their learning (Poli, Serino, Mars, & Hunnius, 2020; Twomey & Westermann, 2018). These sampling strategies are especially important as children come into the world equipped with rudimentary learning mechanisms and limited cognitive resources (Kidd et al., 2012, 2014): By using those limited resources optimally instead of giving equal attention to all stimuli, children can maximize information gain.

One active learning strategy that children employ to sample from the learning environment aims to maximize learnability: If children allocated equal attention to all kinds of input in their environment, learning would be limited, as not all sources provide equally learnable information. That children instead selectively attend to the stimuli that provide optimal learning opportunities has been shown by Kidd et al. (2012, 2014) with regard to auditory and visual processing in infants as young as 7 to 8 months. Children were exposed to visual and auditory sequences of varying complexity, ranging from highly predictable to unpredictable. In both modalities, infants preferentially attended to sequences of medium complexity, a behaviour that suggest a domain-general principle of attention allocation: Children maximize learnability from the environment by actively seeking out stimuli at the sweet spot of predictability in order not to waste cognitive resources on overly simple – i.e. already known – or overly complex – i.e. unlearnable – information. Evidence for this Goldilocks effect has also been found in an infant ERP study with 9-month-olds (Linnert & Westermann, 2020), highlighting the underlying neural processes of infants' preference for intermediate novelty.

What children know will shape what they learn

While the Goldilocks theory explains why children preferentially attend to some stimuli over others, is it also a suitable approach to explain why children learn some words rather than others? A Goldilocks approach would predict that children preferentially attend to and add words to their lexicon that are of intermediate novelty, a property that can be controlled for in a laboratory-based word learning task (cf. Horst et al., 2011). But what role do novelty and complexity play in word-learning situations that either take place in the real world or are modelled after real-life situations in the sense that they present actual objects to the child (e.g. Borovsky, Ellis, Evans, & Elman, 2016a)? New words encountered in the real world do not exist in a vacuum, but are usually part of a semantic category and share conceptual or perceptual features with other – known or yet-to-be-learnt – words. In a real-world word learning situation, the size and structure of the semantic categories represented in a child's lexicon might determine the candidate words that are most learnable: Words form the vertices (or nodes) of a larger network, with connections of varying strength between the nodes. One way to assess the complexity – and therefore, learnability – of a novel word would thus be to determine how easily it can be added to the existing network and how connected it is to the current network vertices. The early lexicon – much like the adult lexicon (Steyvers & Tenenbaum, 2005) – is a semantic network, exhibiting what is known as small-world structure (Beckage, Smith, & Hills, 2011; Hills, Maouene, Maouene, Sheya, & Smith, 2009): Small-world semantic networks are characterized by highly locally-connected clusters of words that are semantically related, reflecting representations of semantic categories at a network level. This structure can be observed in children as young as 15 months with vocabularies consisting of just 55 words (Beckage et al., 2011). Can the structure of a semantic network at a given time predict which words are most likely to enter the lexicon next?

Barabási and Albert (1999) found that new network vertices preferentially attach to already well-connected parts of the network, a growth mechanism also labelled preferential attachment. Preferential attachment eventually leads to a rich-get-richer phenomenon: More vertices are added to already-dense clusters in the small-world network, making them already denser. If the clusters in early semantic networks reflect semantic categories, this suggests that children will not only more readily learn new words that are semantically related to other known words, even more so if the new word is semantically related to a larger cluster. This highlights the role of prior semantic knowledge in word learning: Children might leverage their existing knowledge to acquire new words, a prediction that was tested by Borovsky et al. (2016a). Exposing 24-month-olds to new word-object-associations from dense and sparse semantic categories (according to parental CDI reports), they found that children more robustly recognized novel words from high-density categories.

Thus, a child's prior knowledge and the size of their semantic categories[1] might shape vocabulary trajectories by making certain words more or less likely candidates to enter the lexicon for individual children. Words that are very novel – in the sense that they are semantically related to no or few words in the existing network – are less learnable and therefore less likely to enter the lexicon. With a growing number of known category members, the complexity of the novel word decreases insofar the child can leverage existing knowledge and more easily anchor the new word to the

[1]A similar leverage effect has also been observed with regard to phonological bootstrapping in which children make use of known information to learn new information: Children show better word learning from larger phonetic categories (Newman, Samuelson, & Gupta, 2008) and for words that sound similar to known words (Altvater-Mackensen & Mani, 2013). These findings underscore the importance of prior knowledge in other domains of language development.

known category members – learnability increases. In contrast to the Goldilocks effect of attention, however, the leverage account – which is concerned more with learning than with attention – predicts that learnability increases as a function of category size, showing the divergence of the two approaches.

Borovsky et al. (2016a) determine each child's high- and low-density categories based on how many words from the respective CDI categories the child is reported to say. While the lexical leverage account explains how category size at the time of word learning influences the addition of new words to the lexicon, it does not address the fact that children start out with very differently-sized categories to begin with (Mayor & Plunkett, 2014), bringing us back to *Bagger* babies and *Bär* babies. The words that children know belong to a semantic category, leading not only to differences in the individual words known to a child, but also in the distribution of these words across semantic categories: Bagger babies might actually be VEHICLE babies, while Bär babies might more aptly be named ANIMAL babies, reflecting differences in category size rather than individual items.

What children are interested in will shape what they learn

What is it that determines whether a child is a VEHICLE baby or an ANIMAL baby? As outlined above, a number of factors related to the input that a child receives contribute to these differences in vocabulary structure. However, another possible explanation for individual differences might lie within the child themselves: Children selectively attend to information and structure their learning environment by sampling from the environment. One sampling strategy aims to maximize information gain, e.g. by preferentially attending to stimuli of intermediate complexity. This principle of attention allocation can be observed in infants as young 7 months, who turn away from stimuli that are either too simple or too complex (Kidd et al., 2012, 2014). But children can also take an even more active part in imposing structure on a messy learning environment, namely by actively requesting information from an adult.

From early on, children direct their caregivers to provide information – such as the label or function – about specific objects in which they are interested. Preverbal infants use pointing gestures that have historically been assumed to serve either an imperative or a declarative function (E. Bates, Camaioni, & Volterra, 1975), while recent research highlights the communicative function of infant pointing (Southgate, Van Maanen, & Csibra, 2007; Tomasello, Carpenter, & Liszkowski, 2007). Begus and Southgate (2012) show that infant pointing additionally serves an interrogative function: 16-month-olds point to elicit information about objects in their environment. Children not only actively request information at an early age; they also retain information better that was provided in response to their request Begus, Gliga, and Southgate (2014). Additionally, adults are more likely to label the objects in the environment that the child points at (Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007; Kishimoto, Shizawa, Yasuda, Hinobayashi, & Minami, 2007), and the amount of infant pointing is also linked to later vocabulary outcomes (Brooks & Meltzoff, 2008).

The benefit of actively recruited information has also been observed more directly with regard to language acquisition and word learning across early development. At 11.5 months of age, children learn the label of a novel object better when it was provided after the infant had uttered a vocalization directed at it (Goldstein, Schwade, Briesch, & Syal, 2010), and at 18 months of age, children show better fast-mapping abilities for objects they had previously pointed to (Lucca & Wilbourn, 2018). In a touchscreen-based word-learning task, preschoolers who were allowed to choose which of two objects they wanted to learn the label for showed better word recognition than their passive counterparts who were not given a choice (Partridge, McGovern, Yung, & Kidd, 2015).

These findings show that an active recruitment of information leads to superior learning, highlighting the importance of the child "at the steering wheel" of their own development and challenging pedagogical accounts (Csibra & Gergely, 2009, 2011) that place the child in a more passive, receptive role: The child actively shapes their learning environment by selectively attending to parts of the input provided by the caregiver.

How does the active request of information relate back to individual differences in early word learning and vocabulary trajectories? Children may actively request the label of a novel object, prompting the caregiver to label it and making it more likely for this word to enter the child's vocabulary. This information-seeking behaviour is related to what the child is interested in, as they will be more likely to request information about objects they consider interesting. Children thereby shape their learning environment according to their own interests: If they preferentially request labels for objects that they find interesting, parents might adjust the input in response (Kishimoto et al., 2007) and give the child an improved learning opportunity: If a child is interested in the object that goes with the label *Bär*, they might prefer to request this specific label from their caregiver over another.

While several studies to-date have examined this interest-based information-seeking at the object level, it could conceivably be extended to the category level, as the ability to group objects into semantic categories emerges early and semantic relations impact the later structure of the lexicon. Children as young as 3 to 4 months group objects into basic-level categories (Eimas & Quinn, 1994), while 7-month-olds have been shown to form superordinate-level categories such as animals and vehicles (Mandler & McDonough, 1993). In addition, children differ early on in their interests in specific categories, e.g. TRAINS, to an extent that caregivers are able to identify and report these interests even in 18-month-olds (DeLoache, Simcock, & Macari, 2007).

These findings on the influence of interest on learning outcomes gives rise to the possibility that word learning is not only influenced by the interest in a particular object, but also by a child's interest in the superordinate category this object belongs to. A child that is more interested in ANIMALS might thus more often request labels for exemplars of this category. This early variability in interests might thus be one factor that explains why we can identify ANIMAL babies and VEHICLE babies at 24 months: Differently sized categories at that age might reflect differences in interest at an earlier age that led to requesting more or less information about a category and its members.

1.3.5 Theoretical considerations

Input-based accounts of variability highlight the importance of the caregiver in shaping a child's vocabulary growth and composition, consistent with pedagogical approaches to language learning that emphasize the role of the parent as an expert teacher: The parent provides the child with ideally-structured input and guides the novice learner through their development (e.g. Csibra & Gergely, 2009). In a pedagogical framework, the child is primarily considered a recipient of information, sensitive to ostensive signals from the caregiver: Caregivers use cues such as eyegaze or infant-directed speech to convey the communicative relevance of information. Natural pedagogy attributes attentional biases to the child that help them learn, but does not explicitly highlight the child's role as an active explorer: Ultimately, learning in a pedagogical framework is highly caregiver-dependent and does not result from spontaneous, curiosity-driven approaches.

On the other hand, recent approaches to learning and development move away from purely input-based explanations of differences towards explanations that take into account characteristics of the individual child as a vital source of variability: By selectively attending to certain stimuli, children structure a cluttered environment and shape their own learning experiences. This idea of the child as an active learner can be traced back to Montessori (1914), who described children as "active and intelligent explorers" (p. 84), echoed by Piaget's (1936; 1952) claims that child development is driven by trying to resolve discrepancies between what the child already knows and what they experience while interacting with their environment. While the idea that children play an active role in their own learning and development dates back more than a century, research has only recently started examining the mechanisms underlying what is commonly called active or curiosity-driven learning, as outlined above.

Children undeniably explore their surroundings, driven by their own curiosity, but are also still highly dependent on their caregivers due to their limited cognitive and motor abilities. This duality of autonomous exploration and dependency gives rise to the possibility that input-oriented and curiosity-driven approaches are highly interconnected. Children explore their surroundings and develop an interest in objects and categories in their environment. If the caregiver is aware of the child's interests, they might alter subsequent input accordingly, simultaneously responding to and potentially furthering the child's interests.

1.4 Interest and curiosity

As outlined above, children's interests shape what they will request information about, and in turn, what they will learn. It has also been shown that children's learning and exploration is in part driven by their curiosity. Thus, both interest and curiosity play important roles in early learning and development – but are they one and the same? *Interest* and *curiosity* are sometimes used as synonyms or near-synonyms not only in everyday language, but also in the scientific literature (e.g. Lucca & Wilbourn, 2018), giving the impression that both words refer to the same underlying concept. Indeed, curiosity and interest are hard to distinguish at a behavioural level as they lead to very similar observable outcomes, such as exploratory behaviour and heightened attention towards a stimulus (Ainley, 2019).

There has been an ongoing debate about the exact definitions and delineations of the two terms in psychology and neuroscience (cf. Ainley, 2019; Grossnickle, 2016; Kidd & Hayden, 2015). While there is consensus in the literature that the two concepts are related, there is disagreement concerning the extent of their overlap – from researchers claiming that the two terms, in fact, refer to the same underlying mechanisms (Silvia, 2006, 2008, , followingBerlyne, 1960), to those who explicitly set out to disentangle the two concepts (Grossnickle, 2016). Importantly, curiosity and interest have both been identified as driving forces in learning and development (Hidi & Renninger, 2006; Kang et al., 2009). While this thesis does not aim to resolve longstanding debates on the nature of curiosity and interest, it is still worthwhile to take a closer look at both concepts, their boundaries and their potential relation to early (word) learning.

1.4.1 Interest

Interest has been characterized as "the psychological state of engaging or the predisposition to reengage with particular classes of objects, events, or ideas over time" (Hidi & Renninger, 2006, p. 112). While curiosity is often conceptualized in terms of uncertainty reduction and some definitions of curiosity highlight its potential negative emotional component (see below), interest is generally seen as a positive motivator for learning (e.g. Hidi & Renninger, 2006). However, much like curiosity, interest, has been shown to positively influence attention (e.g. Hidi, 1995; McDaniel, Waddill, Finstad, & Bourg, 2000) and learning outcomes (e.g. Hidi, 2001).

Much of the research on interest to-date focuses on older children and is rooted in educational psychology, where interest is usually examined against the backdrop of learning in an academic setting and in relation to academic performance (e.g. Hidi & Harackiewicz, 2000; Lipstein & Renninger, 2006). Potentially due to the difficulties in assessing interest in pre- or just verbal children (see [below]), research on the emergence, nature and development of interest(s) in younger children is limited: School-age children can self-report their interest in certain domains, while younger children's interests have to be inferred from observation or parental report. In a study with children aged 2 to 4 years, Renninger and Wozniak (1985) identify some characteristics of interests in young children that are echoed by DeLoache et al.'s (2007)study on EIIs in children aged 11 months to 6 years: Children show considerable individual interests early on, their interests are relatively stable across a longer period of time, and they will preferentially engage with objects from categories or domains that they are interested in. DeLoache et al. (2007) find that children will engage with their interest domains by repeatedly talking about categories of interest, requesting information about category members, and seeking out category exemplars in their environment.

The interests observed and reported by parents in DeLoache et al. (2007) are individual interests, characterized by a predisposition to repeatedly engage with objects from the interest domain over longer periods of time. As hinted at in the definition of interest quoted above, however, interest – similarly to state and trait curiosity – operates at different timescales: Hidi and Renninger (2006) differentiate individual interest from situational interest, a short-lived state characterized by heightened attention to a particular external stimulus. In their four-phase model of interest development, Hidi and Renninger (2006) identify four distinct phases through which interest progresses from triggered situational interest to well-developed individual interest (see Figure 1.1).

The first phase, *triggered situational interest*, is defined as a short-term, in-the-moment response to a surprising or incongruous stimulus, mirroring definitions of curiosity that focus on novelty and incongruity. This first phase might then be

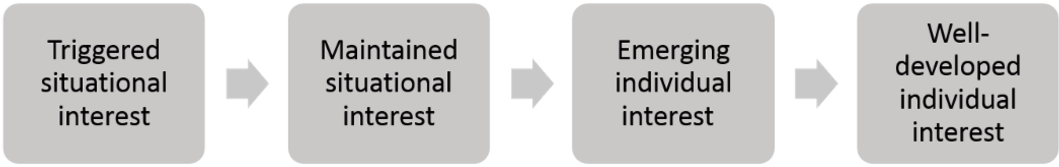


Figure 1.1: The four phases of interest development as identified by Hidi and Renninger (2006).

followed by a state of heightened attention to a task or stimulus over a longer period, termed *maintained situational interest*.

While the two phases of situational interest are fleeting states that usually occur in response to a stimulus, individual interest is described as a predisposition rather than a state. In the third phase, *emerging individual interest*, the learner starts to engage repeatedly with the interest domain even in the absence of a relevant stimulus. Importantly, this phase is characterized by curiosity questions (cf. also Ainley, 2019): By asking questions about the interest domain, the learner seeks to deepen their knowledge and understanding of a topic (Renninger, 1990). Lastly, *well-developed individual interest* is defined as a stable predisposition to reengage with content from the interest domain, characterized by question-asking behaviour, positive feelings towards the interest domain, and, importantly, increased knowledge.

If we argue that children request information based on their interests and that interests shape what they will learn, we have to distinguish these two types of interest and their potential influence on learning. On the one hand, children could request information about objects that they are situationally interested in, i.e. objects whose properties triggered their interest in a given moment. An interrogative pointing gesture (Begus & Southgate, 2012) could thus be reflective of situational interest: An object in the environment has caught the child's attention, which leads them to request more information about it. On the other hand, the same gesture could be interpreted as an expression of individual interest: The child requests additional information because they identify the object as belonging to a category of interest, e.g. ANIMALS. Similarly, either type of interest could drive word learning in a given situation. Different measures of early interest, as outlined below, could tap into these timescales and shed light onto the contributions of both types of interest.

1.4.2 Curiosity

In everyday life, young children are often described as curious learners who try to understand the world around them by exploring their surroundings (Wallace, 2015), and their natural curiosity is framed as something to be encouraged (Leslie, 2014). This view highlights two components of curiosity – its relation to exploratory behaviour and its influence on learning and development – that people commonly associate with the concept of curiosity but does not do justice to ongoing debates in psychology and neuroscience on the nature and definition of curiosity.

While there is agreement that the psychological concept of curiosity can broadly be described as a "desire for information" (Kidd & Hayden, 2015, p. 449) and that curiosity is associated with enhanced learning (e.g. Gruber, Gelman, & Ranganath, 2014; Kang et al., 2009; Stahl & Feigenson, 2015), the mechanisms underlying curiosity have been described as "poorly understood" (p. 449) in the literature to-date. Kidd and Hayden (2015) highlight the fact that there is no widely agreed upon operational definition of curiosity, an observation that goes hand in hand with the ongoing discussion about what does and does not count as curiosity. The following will briefly review some core components and proposed causes of curiosity together with several dimensions along which different types of curiosity can be distinguished, namely epistemic vs. perceptual curiosity and interest-type vs. deprivation-type curiosity.

Components and dimensions of curiosity

Despite the vagueness surrounding the term, certain components of curiosity have been identified in the literature and resurface in various definitions of the term. These components include information-seeking and exploratory behaviour, engagement with novel or surprising stimuli, and the need or desire to acquire new knowledge or information (Grossnickle, 2016). One of the earliest definitions of curiosity as a psychological concept dates back more than 100 years to James (1899) who described infant curiosity as follows:

"Novelties in the way of sensible objects, especially if their sensational quality is bright, vivid, startling, invariably arrest the attention of the young and hold it until the desire to know more about the object is assuaged." (James, 1899, p. 72)

James' (1899) description already contains the core components also identified by Grossnickle (2016): Young children will attend to and engage with novel stimuli until their need for information is satisfied.

Subsequent research then set out to explore curiosity and its causes in more detail. Curiosity proved to be a multi-faceted, difficult-to-grasp phenomenon, which has led to a differentiation of various subtypes of curiosity and a variety of proposed causes. Early theories conceptualize curiosity as a drive (e.g. Pavlov, 1927) that – like other drives such as hunger – can be satisfied (cf. Loewenstein, 1994, for a review). Importantly, these drive theories also proposed and empirically examined a link between curiosity and physiological markers of heightened arousal such as increased muscular tension (e.g. A. Smith, 1953; Wallerstein, 1954), which also has implications for potential measures of curiosity in young children.

These observations led Berlyne (1954) to propose the optimal arousal model: In order to attain a pleasurable optimal level of arousal, people will engage in exploratory behaviour both when over- and underaroused. In the case of underarousal, people are motivated to explore the environment in search of new stimuli (also termed diversive curiosity), while overaroused people will seek out a specific piece of (missing) information in order to lessen arousal. This assumption of an optimal level of incongruity is also echoed in the Goldilocks theory of infant attention (Kidd et al., 2012, 2014) outlined above. Berlyne (1954) was also the first to distinguish epistemic and perceptual curiosity, i.e. a desire for knowledge and a desire for sensory experiences, respectively.

The desire for a particular piece of information links back to James' (1899) description, as both draw attention to another important aspect of curiosity, namely its potentially negative emotional component. While interest is commonly characterized as positive, some definitions of curiosity explicitly highlight the aversive nature of curiosity. This view also features prominently in Loewenstein's (1994) information-gap theory: Epistemic curiosity arises when what one wants to know is above the current state of knowledge. The learner perceives a gap between their current knowledge and the state of knowledge they want to attain, which leads to a feeling of deprivation and dissatisfaction. Motivated to eliminate the unpleasant feeling of deprivation, the learners seeks out the missing pieces of information and closes the information gap. In this model, curiosity itself is considered aversive, but closing the information gap is seen as rewarding and pleasurable, which explains why people voluntarily subject themselves to curiosity-inducing situations.

In an attempt to reconcile Loewenstein's (1994) information-gap theory and Spiegelberger and Starr's (1994) interest model of curiosity, Litman and Jimerson (2005; 2004) propose the interest/deprivation (I/D) model of curiosity. The I/D model of curiosity differentiates two types of curiosity – curiosity as feeling-of-deprivation (corresponding to Loewenstein's conceptualization of curiosity as aversive) and curiosity as feeling-of-interest (CFD and CFI) – that map on to the neurobiological concepts of wanting and liking respectively. While individuals might encounter situations in which they experience CFD and want to obtain information in order to close an information gap, they might also find themselves in situations where there is no perceived information gap, but they would still enjoy learning new information, i.e. they experience CFI.

Models of infant curiosity

How do these different theories and conceptualizations relate back to exploratory behaviour and learning in young children? While it has been shown that curiosity is positively related to learning outcomes in adults (Gruber et al., 2014; Kang et al., 2009) and that children take an active role in their own learning by selectively attending to their environment and requesting information (see [above]), little is known about the precise role of curiosity as a driving force of development. Neurocomputational and robotic models of early development can give insight into the role of curiosity in learning.

Twomey and Westermann (2018), who define infant curiosity as "intrinsically motivated novelty minimization in which discrepancies between stimuli and existing internal representations of those stimuli are optimally reduced" (p. 3), reiterate the importance of novelty and uncertainty reduction, while also drawing attention to the role of intrinsic motivation in curiosity-driven exploration. Twomey and Westermann (2018) stress that the novelty of a stimulus is subjective to the learner and determined by their previous learning history, echoing the importance of an individual's previous knowledge in selecting learning experiences. Their neurocomputational model of infant visual categorization supports this assumption: Learning outcomes are best when the model takes into account and maximizes this subjective novelty while also considering the current learning environment. Importantly, the model's curiosity-based exploration is intrinsically motivated, i.e. not driven by an external reward. This links back to observations of intrinsically-motivated exploration in early infancy (e.g. Schlesinger & Amso, 2013; Schlesinger, Amso, & Johnson, 2007) and the idea already proposed by Berlyne (1954) that the experience of information gain could be rewarding in and of itself.

This assumption has implications for active learning in infancy: Children actively seek out those learning experiences that offer maximized learning opportunities depending on their prior state of knowledge, as this maximized learning is seen as most rewarding. In this model, learning progress determines what is most learnable at a given point, and the learner will choose learning experiences that maximize learnability in the moment. Importantly, this view uncouples subjective novelty from objective measures of complexity (as proposed e.g. by Kidd et al., 2012, 2014) and goes beyond deprivation-type models of curiosity (e.g. Loewenstein, 1994), as it accounts for spontaneous exploration that temporarily increases uncertainty. This model moves away from explanations that rely on objective measures of novelty and/or complexity and takes into account the learner's individual learning history and progress.

The idea that learning progress plays a central role in curiosity-driven exploration also lies at the core of the learning progress hypothesis (LP hypothesis, Oudeyer, Gottlieb, & Lopes, 2016; Oudeyer & Smith, 2016). Similar to the model proposed by Twomey and Westermann (2018), the LP hypothesis assumes that the learner is intrinsically motivated to seek out those learning opportunities that allow for an improvement of predictions: The learner will preferentially engage in activities "just beyond its current predictive capacities" (mirroring Vygotsky's 1980 idea of the zone of proximal development) that provide maximized reduction of prediction errors. In contrast to other models (e.g. Kang et al., 2009; Stahl & Feigenson, 2015), the LP hypothesis proposes a feedback loop between learning and curiosity instead of a unidirectional causal chain: Learning progress – the minimization of prediction errors – is rewarding in itself, and experiencing this rewards causes the learner to seek out additional opportunities to further reduce prediction errors. This has long-term consequences for shaping developmental trajectories: As learning progresses, the learner will shift their focus from simple activities to more complex ones in a way that maximizes learning progress and reward. The LP hypothesis was put to test in a robot model of vocal learning (Moulin-Frier & Oudeyer, 2012): The robot's curiosity-driven exploration of the vocal tract, intrinsically motivated to maximize learning progress at each step, led to a developmental trajectory that mirror infants' phonetic learning.

Taken together, these insights from neurocomputational and robotic models highlight the importance of the child's current knowledge and prior experiences: Children's experience of state curiosity is not only driven by objective properties of the stimulus (such as quantified complexity) or the need to close a knowledge gap (Loewenstein, 1994). Instead, children are intrinsically motivated to seek out and learn from novel stimuli, as learning itself can be rewarding. This assumption is corroborated by recent research on reward-based learning in adults (Ripollés et al., 2014; Syal & Finlay, 2011). Children might thus be intrinsically motivated to acquire a language and learn words. Which words they learn at a given time would be influenced by the subjective novelty and potential learning progress associated with the candidate words, reinforcing the importance of previous knowledge in the learning process.

1.4.3 Overlap and influences

Curiosity and interest lead to similar observable behavioural outcomes in children, namely exploratory behaviour, heightened attention, and better learning outcomes, making experiential states of curiosity and interest hard to distinguish. However, as Ainley (2019) notes, the concepts of curiosity and interest diverge at larger timescales. While curiosity is a relatively stable character trait across the lifespan, individual interests are more flexible and always tied to specific content: While we might describe a child as curious, referring to their general propensity of experiencing curiosity, we would not describe a child as interested. Instead, people are said to be interested in something, highlighting the relevance of interest domains. Although individual interests are relatively stable over longer time periods, they might shift to different interest domains as children grow older.

At the same time, however, (state) curiosity and interest are intertwined in interest development: In the later phases of interest development, as proposed in the four-phase model (Hidi & Renninger, 2006), the learner will ask curiosity questions about their interest domain (Johnson, Alexander, Spencer, Leibham, & Neitzel, 2004). This suggests that repeated experiential states of curiosity in which children ask questions and seek out information are vital to deepening and maintaining individual interests.

This relates to the role of prior knowledge in curiosity and interest, a factor that has been used to differentiate between the two concepts. Engel (2011) points out that children's curiosity is often directed towards novel stimuli from domains that they are already somewhat familiar with and interested in. This links back to the theories of curiosity outlined above that emphasized the importance of a knowledge gap in the sense of Loewenstein (1994) or in the sense of an optimal incongruity that maximizes learning progress (Oudeyer & Smith, 2016; Twomey & Westermann, 2018). In line with the Goldilocks theory, this suggests that curiosity as a function of knowledge follows an inverted U-shape, a prediction that is supported by the findings of Kang et al. (2009). In contrast, models of interest propose a linear relationship between knowledge and interest (Hidi & Renninger, 2006): With increased interest, the learner will deepen their knowledge about the interest domain. Dynamic models that take into account learning progress can account for this apparent discrepancy: According to the LP hypothesis (Oudeyer & Smith, 2016) or the model proposed by Twomey and Westermann (2018), what is optimally incongruent changes as overall knowledge increases.

Curiosity and interest in early childhood share many characteristics and must be seen as tightly linked concepts. From early on, children differ with regard to their interest domains to an extent that caregivers can notice and report these individual differences. At the same time, individual children will experience states of curiosity within their interest domains or categories, triggered by encountering stimuli that allow them to learn and deepen their knowledge. Their previous experience with and knowledge of a domain determines to what extent they can learn from a novel stimulus, which in turn influences if and to what extent they experience curiosity.

1.5 Measurements

1.5.1 Measuring interest - From parental reports to pupillometry

Interest has been shown to influence children's learning outcomes at various stages of development, but how do we measure interest in developmental populations, especially at an age where children have not yet learnt to reliably communicate their interests verbally? While older children can rate their interests in particular topics (e.g. Ainley, Hidi, & Berndorff, 2002), interest in infancy and early childhood cannot reliably be assessed through self-report measures.

One way to measures interest is through parental report: In their study extremely intense interests, DeLoache et al. (2007) asked parents to report what their children are interested in. This measure of interest, however, assumes a certain reliability of parental reports: Caregivers have to actually be aware of their children's interests, and respond to questions in the way researchers intend. DeLoache et al. (2007) asked caregivers to report "only the most intense interest their child had ever had" (p. 1580), leading to parents to base their report on behaviours displayed and observed on longer timescales. This fits with Hidi and Renninger's (2006) stage of well-developed individual interest in their four-phase model of interest development. This final stage of interest development is characterized by repeatedly engaging with the relevant object or category as well as question-asking behaviour. This makes parental reports a valuable measure of long-term, stable interest domains.

However, Hidi and Renninger (2006) also identify precursors to this well-developed individual interest that are more fleeting in nature and not necessarily as accesible or easily identifiable to an outside observer. Situational interest, for instance, as defined by Hidi and Renninger (2006) is characterized by an in-the-moment response to an external stimulus. For interest to arise, it is not necessary that the stimulus be present for a long time – a short exposure to something that triggers the child's interest is enough. It is, however, questionable whether caregivers would notice such a short-lived moment of interest, let alone identify it as such.

To tap into these fleeting occurrences of interest, other, more direct measures of infant interest would therefore be desirable. One such recent approach to measuring pre- and barely verbal children's internal states is pupillometry, i.e. the measure of children's pupil dilation in response to certain stimuli.

The human pupil responds to changes in ambient light: Bright light leads to pupil constriction, while the pupil dilates in low light. In addition to this purely physical reaction, however, pupil dilation has also been shown to reflect activity in the autonomous nervous system, i.e. emotional or cognitive reactions to external stimuli. Research with adult and clinical populations has capitalized on the pupillary measure for decades (cf. Bradshaw, 1967, and Kahneman & Beatty, 1966, for early examples, Sirois & Brisson, 2014 for a review).

However, pupillometry only recently – together with improved eyetracking technology and automatic meausrement of pupil size by modern eyetrackers – made its way into research with developmental populations (see Hepach & Westermann, 2016, for a review). In the last decade, pupil dilation measures have since been used to address a range of questions in infancy research (e.g. Gredebäck, Eriksson, Schmitow, Laeng, & Stenberg, 2012; Hepach & Westermann, 2016; Sirois & Jackson, 2012).

Pupillometry offers certain advantages in comparison to other established measures such as looking time: Changes in pupil dilation are both time-locked to the onset of a stimulus and dynamic in nature, allowing for a more fine-grained exploration of the onset and time course of infants' reactions to critical events (e.g. Gredebäck et al., 2012; Hepach & Westermann, 2016; Sirois & Jackson, 2012). At the same time, however, Hepach and Westermann (2016) note that pupillary measures should always be interpreted with caution with regard to underlying psychological processes, as different cognitive and emotional states have been shown to cause the pupil to dilate. It is therefore not possible to map observed pupil dilation directly onto an assumed underlying process.

Although a direct mapping of pupil dilation and interest is not possible, pupillometry is nonetheless a strong contender for a more direct measure of children's interests in objects and categories. Several studies have shown links between the pupillary measure and certain processes commonly associated with curiosity and interest, such as novelty (Bonmassar, Widmann, & Wetzel, 2020), surprise (Preuschoff, 2011), and heightened attention (Jackson & Sirois, 2009). Additional support for a relation between pupil dilation and curiosity or interest comes from a study with adult participants (Kang et al., 2009) that found a positive correlation between participants' pupil dilation and their self-reported curiosity. Importantly, pupil dilation "first and foremost assess internal arousal" (Hepach & Westermann, 2016, p. 16), i.e. the emotional response to the stimulus presented. This relation between pupil dilation and internal arousal has been examined extensively in the literature with developmental and adult populations (e.g. Bradley, Miccoli, Escrig, & Lang, 2008; Bradshaw, 1967; Hepach, 2017; Urai, Braun, & Donner, 2017; Yucel, Hepach, & Vaish, 2020). As outlined above, curiosity and interest have both been linked to heightened arousal, allowing for a cautious interpretation of the pupillary measure as an index of interest in the stimulus.

In comparison to parental reports of interest that are based on long-term behaviour, pupil dilation captures an immediate, short-lived response to a stimulus in a particular moment. It could be argued that the two measures tap into the different timescales of curiosity and interest outlined above. Applying and comparing both measures of infant interest in the same studies will thus shed further light onto the role of in-the-moment arousal and long-term interest in word learning.

1.5.2 Measuring word recognition - Preferential looking

The studies presented in this thesis require us to assess children's word learning. One common way of measuring young children's language comprehension, the intermodal preferential looking paradigm (IPLP), capitalizes on children's tendencies to fixate a named object. First introduced by Golinkoff, Hirsh-Pasek, Cauley, and Gordon (1987), the IPLP presents children with two pictures – one target and one distractor – side-by-side on a screen and an auditory prompt to look at the target picture. Children's proportion of target looking (PTL) is then taken as an indicator of successful word recognition. PTL is the proportion of looks to the target divided by looks to both the target and the distractor. If children recognize a word, they show a PTL significantly greater than 0.5, as this indicates that they look more to the target than to the distractor. A PTL around 0.5, on the other hands, indicates that children look at both pictures equally, while a PTL lower than that indicates a distractor preference. This paradigm has proven popular as it does not require the child to respond to the prompt verbally or by pointing, thereby reducing the complexity of the task and making it particularly suitable for infants and toddlers (Golinkoff et al., 1987; Golinkoff, Ma, Song, & Hirsh-Pasek, 2013).

Stimuli in the IPLP are typically presented over a period of several seconds and children's target fixations are not uniformly distributed over the entire time course of the trial. It typically takes children around 240 ms (Swingley, Pinto, & Fernald, 1998) to initiate a fixation in response to an auditory stimulus. Children then fixate the target object for a certain amount of time, before looking away from the target towards the end of the trial (cf. Eiteljörge, 2019, for expected and typically observed PTL time courses).

While the original IPLP was carried out using video recordings that were coded for gaze direction manually, the studies presented here use a screen-mounted eye-tracker (Tobii X120) that automatically determines the child's gaze position on the screen with a sampling rate of 120 Hz and simultaneously records the child's pupil diameter. This gaze position, indicated by x and y coordinates, can then be translated to the part of the image that the child is looking at. To compute PTL in this design, we define two areas of interest (AOIs), namely the target and the distractor, and for each fixation determine whether the child is looking at either of the two areas.

1.5.3 Measuring vocabulary size - The MBCDI

The size of early vocabularies is usually determined by administering a localized version of the MacArthur-Bates Communicative Development Inventory (MBCDI, Fenson et al., 1994). In the studies presented here, we administered the FRAKIS (Szagun et al., 2009) for German-learning children. These parent-report instruments provide caregivers with a list of words and asks them to indicate for each word whether their child understands or understands and produces it. As such, the CDI is a selection of words and cannot necessarily fully reflect each child's true vocabulary at a given time: As children grow older and their vocabularies expand, a pre-defined list of words does not do their individual lexicon justice. Therefore, we asked parents to report any other members of the categories used in the studies that their children produce or understand. Despite these limitations for older children, CDI data can

Table 1.1: Summary of the three studies presented in this thesis.

	Study 1	Study 2	Study 3
Age group	30 months	24 months 38 months	30-36 months
Referential ambiguity	No	No	**Yes**
Time of test	Immediate	**Immediate and delayed test**	Immediate

be used to measure central tendencies of vocabulary development at a group level (Frank et al., 2020).

1.6 Outline

Young children are remarkable word learners whose vocabularies grow many times over during the second and third year of life. This period of accelerated vocabulary growth is also characterized by individual differences in vocabulary composition: While the overall pattern of lexical development remains relatively stable across children and languages, we observe considerable variability with regard to the individual words known to individual children.

This dissertation sets out to shed new light on variability in the early lexicon across three studies. Historically, differences in vocabulary composition has mainly been explained in terms of input. However, recent renewed interest in the child as an active learner provides a promising backdrop against which early word learning can be examined: As children structure their own learning environment by preferentially attending to and learning from stimuli that interest them, it seems strikingly intuitive that word learning is also shaped and modulated by interest. This thesis will examine the influence of interest not only in an object but also in a superordinate semantic category on different aspects of early lexical acquisition, as summarized in Table 1.1.

In Study 1 (chapter 2), we investigate the influence of object interest and category interest on the recognition of newly-learnt word-object associations in 30-month-old children. This study builds on findings that children's learning about objects is enhanced when they requested information about the object themselves, i.e. showed interest in the object. Here, we extend the examination of interest to the category level and test the strikingly intuitive hypothesis that being interested in a semantic category, e.g. ANIMALS, leads to superior learning from this category compared to others. In this eyetracking study, children were first exposed to a total of 16 familiar objects from four early-acquired semantic categories. Their pupillary response to pictures of familiar category members was measures and interpreted as an index of interest. Additionally, parents were asked to rate their children's interests. Children were then exposed to a picture of one novel member of each category and the corresponding novel label. Again, we measured their pupillary response as an index of interest in the novel object itself. Their recognition of the new word-object associations was tested immediately after exposure, using the intermodal preferential looking paradigm.

This study allows us to assess the influence of interest at the object and category level on forming new word-object-associations. It is the first study to look at the role of category interest in early word learning. As variability in the composition of early vocabularies is evident in the literature (Borovsky et al., 2016a; Mayor & Plunkett, 2014), Study 1 aims to clarify the role that interest plays in establishing new word-object associations, and eventually in shaping the size and structure of semantic categories in individual vocabularies.

Study 2 (chapter 3) builds on Study 1, using the same stimuli and the same measures of interest. However, the two studies differ with regard to when children's recognition is tested: While Study 1 tests recognition of the newly-learnt word-object-associations immediately after exposure, Study 2 adds two delayed testing phases after five minutes and 24 hours. As word learning is a complex process operating at multiple timescales, not all initially formed word-object associations enter the child's lexicon. Therefore, delayed recognition in the absence of contextual support has been identified as a test of word learning (Horst, 2017). So far, evidence for successful retention in laboratory word learning tasks is limited Bion et al. (2013); Horst and Samuelson (2008). Adding two retention phases allows us to assess object interest and category interest at this longer timescale, further adding to our understanding of the role of interest in shaping the early lexicon. Moreover, we tested two age groups in Study 2, namely 24-month-olds and 38-month-olds, as word retention skills have been shown to develop during the third year of life. This allows us to re-examine the developmental trajectory of word retention against the backdrop of interest-driven learning.

Study 3 (chapter 4) investigates the role of interest in resolving a referentially ambiguous word learning situation. In contrast to Studies 1 and 2, in which the mapping of the novel word to the novel object was unambiguous, Study 3 exposes children to two new objects at the same time, while only providing one novel label. In their everyday learning environment, children constantly face referential ambiguity in cluttered visual scenes (cf. Clerkin et al., 2017) and use a variety of external cues as well as internal biases (Horst et al., 2011) to determine the correct referent of a novel word. In this study, we eliminate external cues in order to investigate to what extent referent selection is guided by children's interest. We first exposed children aged 30 to 36 months to familiar and novel category members and measured their pupillary response. In a next step, we showed them two novel objects simultanously while only providing one label, creating an ambiguous learning situation. Three interest measures - relative looking time during the ambiguous learning phase, category interest and object interest as indexed by the pupillary measure - were used to determine the most likely referent. In a test phase, we examined to what extent these interest measures guided referent assignmet, allowing us to investigate the role of interest in the absence of external cues.

In chapter 5, the empirical findings will be summarized and discussed in light of the current literature on word learning, interest and curiosity. Limitations of the current thesis and suggestions for future work will be presented.

Chapter 2

Word learning and category interest[1]

2.1 Introduction

Most parents are able to report with some confidence the kinds of things that their children are interested in, as well as track changes in their interest in different natural categories across development. Intuitively, it seems likely that children will know more about the natural categories that they are more interested in. Indeed, recent curiosity-driven approaches to learning suggest that children's interest in individual objects influences their learning of something new about this object (Begus et al., 2014; Begus & Southgate, 2012). However, there are no empirical investigations of the strikingly intuitive possibility that children's learning of a novel word-object association may be driven by their interest in the kind of object a word refers to, i.e., the category to which the object belongs. Here we examine the hypothesis that children learn words more easily when these words refer to members of natural categories that they are more interested in. We suggest that children who are more interested in, e.g., VEHICLES learn novel vehicle labels more easily than children who are interested in ANIMALS, who might, in turn, learn novel animal labels more easily. While the general pattern of vocabulary growth remains relatively stable across children learning different languages, differences in the number of words known to individual children are observable from as early as 8 months. For instance, German

[1]This chapter was published as Ackermann, L., Hepach, R., & Mani, N. (2020). Children learn words easier when they are interested in the category to which the word belongs. *Developmental Science*, 23(3), e12915. doi:10.1111/desc.12915.

vocabulary data (Szagun et al., 2009, the German adaptation of the MBCDI) shows that, at 20 months, 52% of children produce the word Bagger 'digger' and 48% of children produce the word Bär 'bear' (see Mani & Ackermann, 2018, for further discussion). Of the children who produce at least one of these words, 52% of them produce the one but not the other. It is not until 30 months that most German-learning children produce both words. Why are there such early differences in the individual words known to individual children? What determines whether a child is a Bär baby or a Bagger baby (Mani & Ackermann, 2018)?

Several factors contribute to such individual differences (see Mani & Ackermann, 2018, for a review) and much research has examined the extent to which learning about particular objects or in particular situations is driven by the child's interest in these objects or these situations. In keeping with curiosity-driven approaches to learning, research suggests that 16-month-olds actively use pointing gestures to elicit desired information (Begus & Southgate, 2012), and their learning outcomes are better when information is provided in response to their pointing (Begus et al., 2014). The effectiveness of self-guided learning has also been shown in older children: In a touchscreen-based word-learning task, pre-schoolers who were allowed to choose which objects they learned the label for outperformed their counterparts in the no-choice condition (Partridge et al., 2015, but see Kirkorian, Choi, & Pempek, 2016). Together, this work suggests that children actively direct their caregivers to provide them with the labels of objects they are interested in; and retain such information better than information provided at the caregiver's discretion. Here we examine a critical extension to this research, namely, the possibility that children's interest in the kind of object a word refers to, i.e., the category to which the object belongs, may drive their learning of a novel word-object association.

Another factor that might explain differences in the ease with which children learn words from different categories is the size of the category to which the word belongs. Indeed, children learn words from larger phonological categories with greater ease than words from smaller phonological categories (Newman et al., 2008, see Altvater-Mackensen & Mani, 2013); that children learn words more easily when they sound similar to a word they already know). Similarly, a recent study finds that children learn words from broader semantic categories, i.e., categories where they already know many words, with greater ease than words from narrow semantic categories (Borovsky et al., 2016a; Borovsky, Ellis, Evans, & Elman, 2016b).

Borovsky et al. (2016a, 2016b) explain these results in terms of leveraging accounts (Barabási & Albert, 1999) whereby children leverage their existing semantic knowledge to learn new words. However, this account does not explain the early differences in vocabulary size per category, i.e., why there were differently sized categories to start with? We propose a third strikingly intuitive possibility that children learn words for objects because they are interested in the category that this object belongs to. The more interested they are in this category, the more words they will learn in this category, leading to not just differences in category size across different natural categories, but also individual differences in category size across different children.

2.1.1 The current study

Here, we examine whether children's interest in a particular category, e.g., how interested they are in ANIMALS, in general, influences how easily they learn a label for an unfamiliar member of this category, i.e., an unfamiliar ANIMAL. Since children's interest in a category may lead to them knowing more words in this category, we controlled for individual differences in children's category sizes, so that we could examine the independent contribution of category interest on learning. Furthermore, since children who were more interested in one category may also be more interested in the specific category member presented relative to other novel objects, we also controlled for children's interest in the novel members of the different categories presented.

Indeed, an interaction between these factors is a natural result of the findings to-date in the literature: If children learn words more easily for individual objects they are more interested in, then they are likely to know more words in semantic categories that they are more interested in leading to these factors being confounded with one another. Disentangling the individual contribution of these factors on word learning is, therefore, essential to understanding the factors that shape early variability in the words that children know. Thus, we examine how children's interest in a particular category (e.g., ANIMALS), given their knowledge about this category (e.g., how

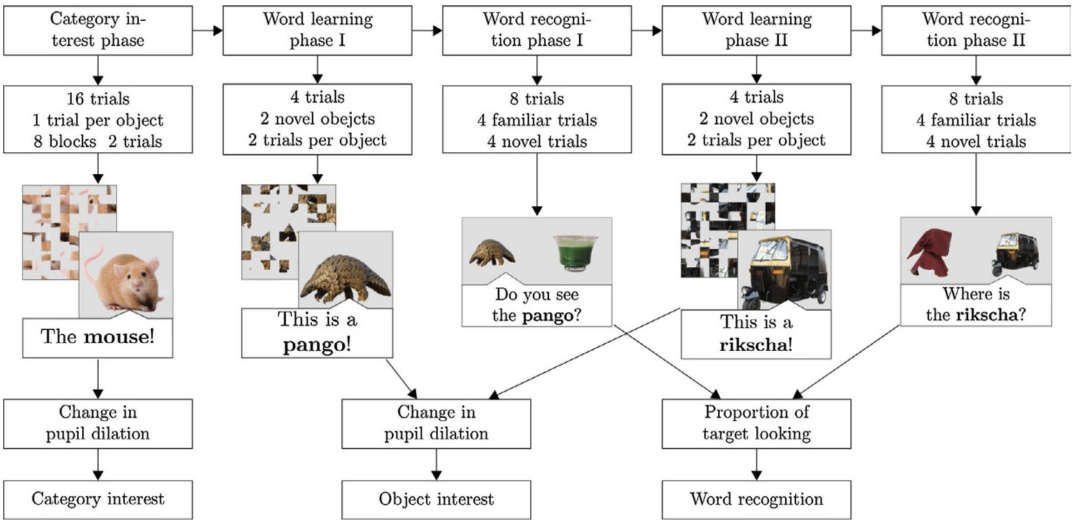


Figure 2.1: Order of study phases with example stimuli and measures for each phase.

many ANIMAL words they know) and their interest in the particular object (i.e., the unfamiliar ANIMAL), shapes learning of novel word-object associations in this category.

The study consisted of three phases (cf. Figure 2.1): a category interest phase, a word learning phase, and a word recognition phase, the last two of which were interleaved and consisted of two blocks, i.e., learning - recognition, learning – recognition. In the category interest phase, we measured children's interest in different natural categories; in the word learning phase, we trained children on four novel word-object associations from four different natural categories; in the word recognition phase, we examined children's recognition of the four learned word-object associations.

We measured interest in a particular category using two measures: First, we asked parents to rate their child's interest in the chosen semantic categories using a seven point Likert scale. Second, in the category interest phase, all children saw 16 objects from four early-acquired semantic categories (ANIMALS, CLOTHES, DRINKS, and VEHICLES) that they were likely to be familiar with and heard the corresponding labels for these objects. We measured changes in children's pupil dilation during this category interest phase – averaged across all members of the category presented – as an index of their interest in a particular category. In other words, we interpreted increased pupillary change following exposure to members of a particular category as increased interest in this category.

The pupillary measure was chosen for the following reasons: The human pupil responds to the presentation of visual or auditory stimuli, reflecting activation of the autonomic nervous system (ANS) and psychological involvement (e.g. Bradley et al., 2008). Changes in pupil dilation have been shown to provide a reliable index of the cognitive processes of pre-verbal or just-verbal children (cf. Hepach & Westermann, 2016; Sirois & Brisson, 2014, for reviews). In developmental populations, pupillometry has been used to examine the dynamics of violation-of-expectation paradigms (e.g. Sirois & Jackson, 2012), individual differences in scanning patterns and processing of emotional facial expressions (e.g. Gredebäck et al., 2012) and questions of social cognition such as helping behavior (e.g. Hepach, Vaish, Grossmann, & Tomasello, 2016). Research with adults finds that pupil dilation and self-reported curiosity were positively correlated and that adults best retained information that they were most curious about (Kang et al., 2009). We also estimated category size, i.e., the number of words children know in each of the categories tested, based on children's individual vocabularies as calculated from parental self-reports of children's vocabularies (Szagun et al., 2009). Thus, while all children saw the same objects and learned the same word-object associations, the assignment of particular categories to particular conditions, e.g., broad or narrow categories based on category size, or high or low interest categories based on differences in children's category interest, varied across children.

Next, in the word learning phase, children were trained on four novel word-object-pairings, one from each of the semantic categories. During this phase, we also measured children's pupillary response to the novel objects as an index of their interest in these individual objects and their labels.

Finally, word recognition and learning were assessed in a word recognition phase using an adaptation of the Intermodal Preferential Looking paradigm (Golinkoff et al., 1987). In this paradigm, successful word learning is indexed by increased fixations to a target image (relative to a distractor image) upon hearing the label for this target (relative to a silent baseline phase). Here, we examined children's recognition of the four newly learnt word-object associations. Interspersed with these trials, were filler familiar object recognition trials, where children were presented with the familiar objects they had been exposed to in the category interest phase.

If children's interest in different semantic categories shapes learning, then children should better learn novel word-object associations in categories they are more interested in relative to categories they are less interested in, as indexed by changes in children's pupil dilation. Similarly, if children's interest in individual objects shapes learning, then children should learn novel word associations for objects they are more interested in relative to objects they are less interested in. Interest in both these cases is indexed by the pupillometry measures outlined above and parental reports. Both findings would yield novel insights on current curiosity-driven theories of early word learning, highlighting the possibility that interest in the kinds of things a word refers to shapes early word learning. If children more readily learn words from broad relative to narrow semantic categories, they should better learn novel word-object associations from broad semantic categories relative to narrow semantic categories, replicating results from earlier studies on lexical leveraging (Borovsky et al., 2016a, 2016b).

2.2 Methods

2.2.1 Participants

Fifty-five children aged 30 months (M = 29 m 18 d, SD = 23 d, range 28 m 4 d – 31 m 14 d, 22 female) were recruited from the institute's database. Nine children were excluded prior to data analysis due to technical errors (N = 6) or being bilingual (N = 3). Of the remaining 46 children, 39 provided data for all critical phases of the study. The other seven children were excluded for not providing enough trials in the category interest phase (N = 2) or not providing sufficient pupil data (N = 5) All children were born full-term, had normal hearing and vision and were reported to be monolingual German learners. Children received a book in return for their participation in the study.

2.2.2 Stimuli

Four categories that typically appear in a German 30-month-old's lexicon were selected from the FRAKIS: ANIMALS, CLOTHES, VEHICLES, and DRINKS. Within each category, we selected four words (each) that are typically known to more than

Table 2.1: Familiar objects used in this study, percentage of 30-months-old children who are reported to know this word (according to FRAKIS data, Szagun et al. (2009)), and percentage of participants (N = 47) reported to know this word.

Category	Object	Known % (FRAKIS)	Known % (participants)
Animals	Mouse	95.70	100
	Crocodile	79.57	97.87
	Ant	75.27	95.74
	Penguin	73.12	95.74
Vehicles	Bus	96.77	100
	Tractor	86.02	100
	Tricycle	83.87	93.62
	Helicopter	82.80	97.87
Drinks	Milk	98.92	100
	Water	98.92	100
	Coffee	87.10	97.87
	Beer	67.74	74.47
Clothes	Pants	97.85	100
	Diaper	95.70	100
	Pajamas	88.17	100
	Scarf	82.80	93.62

50 % of 30-month-old children to serve as familiar objects (Frank et al., 2017; Szagun et al., 2009, see Table 2.1).

One rare member from each of the four categories was chosen as a novel object in each of the categories. The choice of the novel members were based on the following criteria: All items were perceptually similar to typical category exemplars (as in Borovsky et al., 2016a, 2016b, see Table 2.2). Thus, category membership could be inferred based on these perceptual similarities as in previous work on category-based learning in young children (Borovsky et al., 2016a, 2016b). In particular, we chose a pangolin, gugel, rickshaw, and matcha for our novel objects. None of the words referring to these objects (in German) were found in the German CHILDES corpora (CLAN, MacWhinney, 2014), which we took as confirmation of their low frequency in children's everyday linguistic experience. All novel words chosen to refer to these objects were bi-syllabic and conformed to the phonotactic rules of German, namely, PANGO, GUGEL, RIKSCHA and MALPE.

For the set of four novel and 16 familiar items used in the study, a photorealistic representation of each object was selected and placed on a 400 x 400 pixel light grey background. In the *category interest* and *word learning* phases, a scrambled version of

Table 2.2: Novel items from the four categories

Animals	Clothes	Vehicles	Drinks
broad		narrow	
Pango	Gugel	Rikscha	Malpe
			

the image was presented to the child first to control for differences in luminance in our pupillary responses. Images were scrambled using the Scramble Filter plugin for Adobe Photoshop. They were broken up into 100 squares of 40 x 40 pixels each that were then randomly rearranged by the software. Additionally, two types of attention getters were used: a video of blue bubbles in the *category interest* phase and a spinning red flower in the *word recognition* phase.

Auditory stimuli were recorded in an enthusiastic, infant-directed voice by a female native speaker of German at a sampling rate of 44,100 Hz. Noise was reduced and stimuli were normalized to 70 db using Goldwave. Speech stimuli in the *category interest* phase consisted of the object label preceded by the definite article *der*, *die* or *das*. In the *word learning* phase, the novel object label was embedded in five different carrier sentences with a total length of 12.5 s: Schau mal, eine Pango! Das ist eine Pango! Siehst du die Pango? Da ist eine Pango! Wow, das ist eine Pango! ('Look, a pango! This is a pango! Do you see the pango? There is a pango! Wow, this is a pango!'). In the *word recognition* phase, the child was prompted to look to the target object with the target label embedded in one of two carrier phrases, either Siehst du den/die/das [target]? ('Do you see the [target]') or Wo ist der/die/das [target]? ('Where is the [target]?'). The onset of the target word in all test phase stimuli was at 1,020 ms into the test phase of the trial.

2.2.3 Parent questionnaires

At the age tested in the current study, with an average of 31 category members, ANIMALS and CLOTHES are typically broad categories, while VEHICLES and DRINKS

Table 2.3: Absolute number of children who had each of the categories assigned as broad/narrow, high/low category interest, and high/low object interest. Assignment of broad and narrow categories is based on parental report. Assignment of high and low category interest and high and low object interest is based on the median split performed on the pupil data.

	category size		*category interest*		*object interest*	
	broad	narrow	high	low	high	low
animals	39	0	14	22	9	27
clothes	39	0	20	16	23	13
vehicles	1	38	18	16	17	17
drinks	0	39	13	21	16	18

are typically narrow categories with an average of 11 category members each (Szagun et al., 2009). Each participant's vocabulary size was assessed using the FRAKIS, which was mailed to the parents before their laboratory appointment. This allowed us to calculate broad and narrow categories individually for each child. For each participant, the two categories with the highest absolute number of members were treated as broad categories, while the other two were treated as narrow (cf. Eiteljörge, Kriukova, & Mani, 2017, , for a similar approach using absolute measures of category size). If the second and third biggest category had the same number of members (N = 1), both were treated as broad (cf. Borovsky, Elman, & Fernald, 2012). For all other children, animals and clothes were always broad while vehicles and drinks were narrow (cf. Table 2.3). Parents were also asked to report any other members of the four categories familiar to their child, but those additional items were not used to calculate broad and narrow categories as we could not control for differences in parental memory and effort. In addition, no parent reported that their child knew any of the novel items used in the study. The FRAKIS was also used to assess whether the familiar words used in the category interest phase were actually known to the participants.

Parents also received a link to an online questionnaire where they were asked to indicate their child's familiarity with and interest in each of the familiar objects used in the study and the four categories on a seven point Likert scale (1 = not familiar/curious at all, 7 = very familiar/curious).

2.2.4 Procedure

Eye movements and pupil diameter were captured using a Tobii X3-120 eye tracker with a gaze sampling rate of 120 Hz and a pupil diameter sampling rate of 40 Hz. Participants were seated either on their caregiver's lap or in a car seat approximately 60 cm away from a 40 inch screen on which the stimuli were presented using Tobii Pro Studio (version 3.4). Stimuli were displayed over an area of 25 inch diameter in the middle of the screen.

In the *category interest* phase, children saw 16 familiar objects across 8 blocks. Each block presented children with two trials, where both trials within a block presented objects from one category. Thus, one block would present children with two trials, one presenting, e.g., a mouse and the other presenting, e.g., a penguin. After each block, a 10 s video of bubbles was played as an attention getter. The order of blocks presenting objects from different categories was counterbalanced across children. In each trial in each block, the object was first presented scrambled for 2000 ms, then unscrambled for 3000 ms, with the label for the object being presented 1000 ms into the unscrambled phase.

The *word learning* phase was spread across two blocks. In each word learning block, children were presented with two trials each of two of the four novel objects, thus including four training trials per word learning block (with two training trials per object). Within each training trial, children first saw the scrambled image of the novel object for 2000 ms before the unscrambled image was shown for 12.5 s. The object was labelled five times in five different carrier sentences. Since each novel object was presented in two trials, this resulted in 10 labelling events per object across the whole learning phase. During each learning trial, only one novel object was presented on screen and labelled. The pairing of objects and the order in which objects were presented was counterbalanced across children.

The *word recognition* phase consisted of two blocks, the first block succeeded the first block of the *word learning* phase and the second block succeeded the second block of the *word learning* phase (see above). In each word recognition block, children were tested on their recognition of the two novel word-object associations they had been exposed to in the prior learning block. Each block of the *word recognition* phase presented children with a total of eight test trials. Each block included both familiar (n=4) and novel trials (n=4). In each familiar trial, two of the previously seen familiar objects (from the *category interest* phase) were presented side-by-side on screen while children were directed to look at one of these images. We paired objects so that both came from different categories, but each pair either contained two objects from broad or two objects from narrow categories. In each novel trial, the two novel images which has been presented in the immediately preceding word learning block were now presented side-by-side on screen while children were directed to look at one of these images. Thus, each novel object served twice as the target and twice as the distractor. The order of test trials was counterbalanced across participants.

In each test trial, the two objects were presented side by side in silence for 3000 ms, with a gap of 300 px separating the images. Then, a colorful center stimulus appeared onscreen. The test trial only advanced to the next phase once the child was looking to the center of the screen. The two objects then reappeared and the child was prompted to look at the target, with the onset of the target word appearing 1020 ms after the onset of the visual stimulus. The images remained on screen for 2500 ms after the onset of the target word. Areas of interest (AOIs) for the target and distractor were defined as the 500 x 500 px region around the center of the images.

After this first word recognition block, the child was introduced to the two remaining novel objects (second word learning block) and then saw eight test trials again (second word recognition block). The entire procedure lasted 7 to 8 minutes and children received a small book as a thank you for taking part in the experiment.

2.2.5 Preprocessing

Pupil diameter was sampled at 40 Hz. For analysis, pupil data was aggregated into 25 ms bins offline. For each bin, the size of the left and right pupils was exported using pupillary data from only those time bins which were part of fixations and only those time bins with valid eye-tracking data. In a next step, we filtered pupil data using a threshold filter (separately for both eyes), which calculated the difference in pupil size between two adjacent samples and excluded any data points which were in the top ten percent of differences. This excludes large deviations in pupil size from one sample to the next, which are likely to be artefacts. Missing data points were interpolated with a sample size of 4 (Hepach et al., 2016). We then calculated the average pupil size of both eyes. Within each trial pupil diameter was baseline-corrected (see below).

We used pupil dilation during object presentation during the *category interest* phase to measure interest in the categories that the objects stemmed from, i.e., interest in the kind of objects a word referred to. Here, the 500 ms immediately preceding the label served as the baseline[2], while the 2000 ms from label onset served as the window of interest. We chose this window for our main analyses since this taps into a window where children can be sure of what the object refers to, having heard the label, in case there was any doubt as to its identity.

For the *word learning* phase, we took the last 500 ms of the scrambled image as the baseline, while the window between 500 ms after onset of the unscrambled picture and the onset of the label (varying between 1489 and 1912 ms after onset of the unscrambled picture, depending on the target word) was used for analysis. We chose this window for the *word learning* phase in order to ensure that the pupil dilation reflected interest in the object and not the label for this object, since the label was unfamiliar in this phase of the experiment.

To analyze children's eye-movements in the *word recognition* phase, we aggregated gaze data into 40 ms bins offline. In a next step, data points where one or two of the eyes could not be tracked reliably (validity less than 2 on Tobii scale) and trials where more than 80% of the data could not be tracked were filtered out. We adapt this threshold from Borovsky et al. (2016a). This resulted in the exclusion of 9 trials. Only fixations were retained for analysis, using the eye-tracker's automatic classification of eye movements into saccades, blinks, and fixations (looks at a particular AOI more than 60ms). We calculated the proportion of target looking as the total amount of time infants spent looking at the target divided by the total amount of time spent looking at the target and the distractor (PTL). The PTL at each time point in the post-naming phase of the trial, i.e., from 240 ms from the onset of the label (at 1280 ms into the test phase) was corrected for the PTL over the baseline phase, i.e., from 0 to 1020 ms after the onset of the test phase. Baseline correction was carried out as

[2]We also conducted all analyses with the last 500 ms of the scrambled picture serving as the baseline, which yielded similar results (see Table 2.5 for details of this model).

a subtraction of the proportion of target fixations during the entire baseline window from each time point in the test window on a trial-by-trial basis. As is common in the literature (Swingley et al., 1998), we only included data points that began 240ms into the label phase in order to ensure that only fixations which could reliably be considered a response to the auditory stimulus were included in the analyses. The dependent variable in the first analyses reported is the average PTL across the critical test window (1280 to 3020 ms into the test phase), corrected for PTL during the baseline window (from 0 to 1020 ms after the onset of the test phase).

2.3 Results

To examine the effect of *category interest* on target fixations, we first calculated the average baseline-corrected pupil dilation across the critical phase of all *category interest* trials for each of the four categories. We then performed a median-split on pupil dilation data for each child individually, assigning categories to the high *category interest* and low *category interest* conditions respectively. Thus, the two categories where children showed increased pupil dilation to the familiar members of this category (presented during the *category interest* phase) were considered high *category interest* categories, and the two categories where children showed comparatively reduced pupil dilation to the familiar members of this category were considered low *category interest* categories. This was individually calculated for each child, resulting in two conditions per child, namely high interest and low interest categories, containing two categories each. A paired samples t-test then compared the baseline corrected proportion of target fixations during the word recognition phase, across high *category interest* and low *category interest* categories and found that children looked significantly longer at the target when the target was from a high *category interest* category (as established using the pupil dilation measure) compared to when this object was from a low *category interest* category, $t(38)=2.31$, $p=0.026$, 95% CI: .007, .116, $d=.37$. One-sample t-tests examined the effect of recognition, i.e., increase in target fixations from baseline, in each of the conditions, and found significant increase in target fixations from the baseline to the test phase in high *category interest* trials, $t(38)=4.34$, $p<.001$, $d=.69$, but not in low interest trials, $t(38)=1.45$, $p=.156$, $d=.23$. Thus these analyses in conjunction with the means plotted in Figure 2A suggest that children only learned words from high *category interest* trials but not from low *category interest* trials. Taken together, these findings suggest that children learned and recognized novel word-object associations better when the objects belonged to categories they were more interested in relative to categories they were less interested in.

To examine the effect of *object interest* on children's learning of a label for this object, we calculated the average baseline-corrected pupil dilation across the critical phase of all word learning trials for each of the four novel objects. We then performed a median-split on pupil dilation data from the word learning phase for each child individually, assigning each of the four objects to high *object interest* and low *object interest* conditions respectively. Thus, those novel objects which triggered increased pupillary dilation during the word learning phase were considered high *object interest*, and those novel objects which triggered reduced pupillary dilation were considered low *object interest*. A paired samples t-test compared the baseline corrected proportion of target fixations during the word recognition phase across high *object interest* and low *object interest* categories and found no difference in learning from high *object interest* categories compared to low *object interest* categories, $t(38)=-1.19$, $p=0.240$, $d = .19$.

Next, we examined the effect of *category size* on learning. To examine the effect of *category size* on children's learning, we calculated the number of words known to individual children (based on parental reports) in each of the four categories tested. We then performed a median-split on *category size*, assigning categories to broad and narrow conditions respectively. Thus, those categories where children knew more words were considered broad categories, and those categories where children knew fewer words were considered narrow categories. A paired samples t-test compared the baseline corrected proportion of target fixations during the word recognition phase across broad and narrow semantic categories and found no significant difference in learning from broad categories compared to narrow categories, $t(89)=1.69$, $p=0.094$, $d = .27$.

We also examined the relation between interest in the novel category item and interest in the category based on the pupillary measure. The two measures were significantly correlated, $r(140) = 0.198$, $p = 0.019$. Children who were more interested

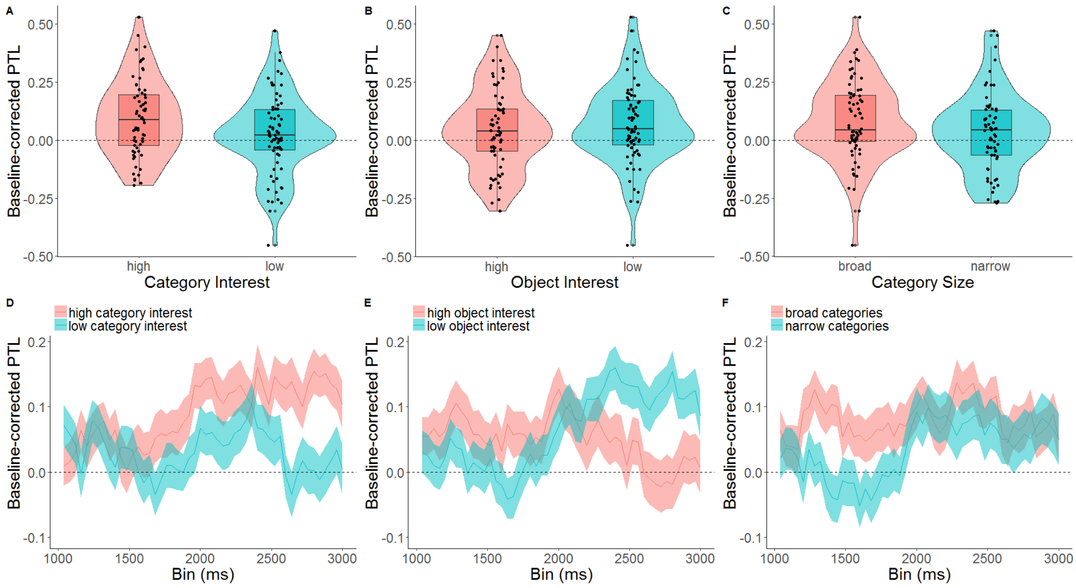


Figure 2.2: Proportion of target looking averaged across the entire time course of the trial (a-c) and for each time point in the trial (d–f) split by category interest (a,d), object interest (b,e) and category size (c,f). p = .026 (a), p = .240 (b), p = .076 (c).

in a particular category were also more interested in a novel item from this category.

2.3.1 Growth curve analysis

While the t-tests suggest that learning is boosted for high *category interest* categories relative to low *category interest* categories and that there were no differences between high *object interest* and low *object interest* as well as broad and narrow categories, these traditional analyses make it difficult to tease apart the contribution of these different factors to the observed pattern. Therefore, in a next step, growth curve models (for a more detailed description, see Mirman, 2014; Mirman, Dixon, & Magnuson, 2008) were used to examine changes in participants' fixations to the target over the time course of the trials. In contrast to the t-tests reported above, growth curve models allow us to examine curvatures in data over time by including Time and its second and third polynomial in the model and modeling the data as a linear, quadratic and cubic function of time. This is especially important for eye movement data: Eye movements are rarely static especially across large time windows like those used in the current study and examining changes across the time course allows us greater depth in understanding infant responding.

Figure 2.2D plots the time course of baseline corrected fixations to the target in the high and low interest conditions during the post-naming phase of the trial.

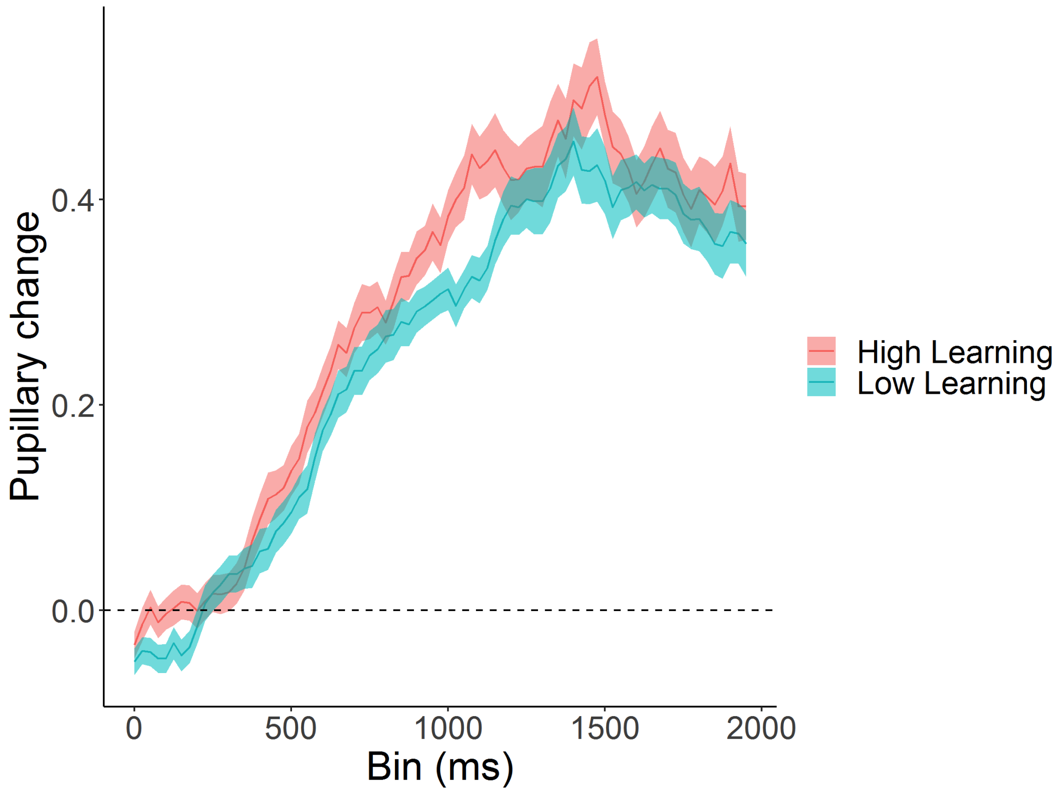


Figure 2.3: Increase in pupil size to familiar objects belonging to the different categories (in the category interest phase) separated by the extent to which children later showed learning of a novel word–object association in each category.

This indicates that children showed increased fixations to the target in high *category interest* trials relative to low *category interest* trials, although they have brief periods where they look at the target above chance in both conditions. Figure 2.3 presents the data from a different perspective, plotting the pupil dilation to familiar objects in the different categories during the *category interest* phase. Here, we split the data based on individual children's learning of a novel word-object association in each category. Thus, the high learning condition in Figure 2.3 presents the pupillary change to familiar objects from those categories (during the *category interest* phase) where individual children later (in the *word recognition* phase phase) showed improved learning of a novel word-object association in these categories. The low learning condition in Figure 2.3 presents the pupillary change to familiar objects from those categories (during the *category interest* phase) where individual children later (in the *word recognition* phase phase) showed less robust learning of a novel word-object association in these categories.

A generalized mixed model was fitted using lme4's lmer function in R (D. Bates, Mächler, Bolker, & Walker, 2015) with Gaussian error structure and identity link function. We used the drop1-function to examine the separate contribution of *category interest*, category size and *object interest* on participants' recognition of word-object associations from the different conditions. This function evaluates the contribution of a factor to the model by comparing a model including this predictor to a model without this predictor ((see Mirman, 2014; Mirman et al., 2008, for clarification).

An effect of category size (broad vs. narrow condition) on all time terms, *category interest* (continuous measure of pupillary change to objects from this category during the *category interest* phase) and *object interest* (continuous measure of pupillary change to individual novel objects during the word learning phase) were included as fixed effects in the model. We included an effect of category size on all time terms given previous findings that category size influences participants' responding in similar tasks. Participant ID and the nested effects of participant ID and category size were included as random effects on the linear and quadratic time terms, which allows for random slopes across participants. We excluded the higher-order polynomial from the random effects since these cause the models to take a long time to run and can lead to difficulties with convergence. We also included a random effect of item on the linear and quadratic time term. We included Time and its second and third polynomial in the model. This allowed us to model our data as a linear, quadratic and cubic function of time and capture according curvatures in the data. The drop1-function revealed significant and independent effects of *category interest*, i.e., interest in the category that the object belonged to, as well as *object interest*, i.e., interest in the individual objects whose labels were to be learned, but no effects of category size on target fixations.

Taken together, the summary of the model presented in Table 2.4 highlights independent effects of *category interest* and *object interest* on learning. There was no effect of category size on learning, and no interaction between category size and any of the time terms. The significant effect on the cubic time term highlights a change in looking behavior (relative to baseline) which has typically been interpreted as evidence for target recognition, and therefore, learning.

In a next step, we examined whether we found a similar effect of *category interest* on word learning, using our measure of parents' curiosity ratings. We fitted a model

Table 2.4: Parameter estimates, standard errors, and p-values for model including category size, category interest, and object interest.

	Estimate	Std. Error	t	p
(Intercept)	0.049	0.026	1.846	0.065
Linear time term	-0.030	0.117	-0.248	0.804
Quadratic time term	-0.028	0.069	-0.410	0.682
Cubic time term	-0.092	0.028	-3.272	0.001**
Category size	-0.047	0.032	-1.468	0.142
Category interest	0.112	0.038	2.947	0.003**
Object interest	0.050	0.020	2.548	0.011*
Category size on linear time term	0.231	0.161	1.439	0.150
Category size on quadratic time term	-0.070	0.090	-0.784	0.433
Category size on cubic time term	0.022	0.040	0.540	0.590

using a third-order polynomial with category size (broad vs. narrow) and *category interest* (as indicated by the parents' ratings) as fixed effects on all three time terms and participant ID, the nested effect of participant ID and category size and category as random effects on the linear and quadratic terms and compared it to a reduced model that did not include *category interest*. Adding parental reports of their child's interest in a category significantly improved overall model fit ($\chi^2(1)$= 12.055, p=<.001) and interest in the category to which the novel object belonged (as reported by parents), as with the pupillary measures, was a significant predictor of the extent to which children learned a label for this object (β=0.012, t=3.683, p=<0.001). Thus, using both pupillary measures and parental curiosity reports, the results suggest that children's interest modulate learning systematically and in a similar manner across both indices tested.

2.4 Discussion

Vocabularies of children as young as 20 months show considerable differences in the individual words known to individual children. While this variability has historically been explained in terms of differences in the input children receive, recent literature places the child in a more active role, showing that children actively seek and retain information best when it is provided at the child's request (cf. Mani & Ackermann, 2018, for a review). Other work has focused on the role of the child's prior semantic knowledge on word learning, suggesting that children more readily learn words from semantically dense categories (Borovsky et al., 2016a, 2016b). The present study examined an alternate but not necessarily mutually exclusive explanation for these differences, namely, that children learn words more easily when they are interested in the kinds of things the word likely refers to: We examined how the child's interest in a particular natural category, i.e., category interest, given her prior semantic knowledge, i.e., category size, and her interest in a particular object, , i.e., object interest, influences learning of novel word-object-associations. Our study yields two main findings: children more easily learn words that refer to the kinds of things they are interested in and children more easily learn words that refer to particular objects they are more interested in.

Using pupillary change following exposure to familiar members of natural categories as one measure of children's interest in this category, the current study found that children more easily learn words for objects that belong to categories they are more interested in. This opens up a new and promising extension to curiosity-centered approaches to learning (Begus et al., 2014; Oudeyer & Smith, 2016; Partridge et al., 2015), which have typically focused on children's interest in particular objects on their learning of a label for this object. Here, we show that children's learning of a novel word-object association is driven by the level of their interest in objects similar to this object. This could play a key role in shaping a child's vocabulary with children who are more interested in animals learning animal labels with greater ease, and therefore, knowing more animal words, which in turn may drive their subsequent vocabulary development.

We found that word learning was similarly modulated by parental ratings of their child's interest in the four categories. Strikingly similar to the pupillary analysis, we found that children learned words better from categories their parents reported them to be more interested in, relative to categories their parents reported them to be less interested in. Aside from supporting the main hypothesis of the current study, this finding also suggests that caregivers are aware of their children's interests, which in turn may impact the learning environment caregivers create for their children. Indeed, the current study focuses on the child and her interests, but does not address the caregivers' role in furthering such interests. Were caregivers to be as aware of their child's interests as the current study suggests, to what extent is it likely they provide increased input on topics related to their child's interests? This might help to critically link curiosity-driven approaches (Mani & Ackermann, 2018) back to input-based accounts with the possibility that the two might be highly interconnected: The child develops her own interests based on the input that she is exposed to, in turn shaping her caregivers' awareness of her interests and subsequent input that she may receive. The child, her interests and the input she receives may, therefore, exist in a perennial loop dynamically shaping the child's environment, her knowledge and interest in particular aspects of this environment.

Interest in a category was not the only factor influencing learning in the current study. While there was no influence of object interest on novel word learning in the more traditional analyses, object interest was a significant predictor of learning in the growth curve analyses (henceforth GCA) reported. As evident from Figure 2.2E, one reason for these disparate results across the two analyses may be that the direction of the effect changes across the trial, highlighting the more fluid nature of the influence of object interest on learning. Additionally, we note that the mixed effects models employed in the GCA allow greater consideration of the variance in children's responding to different objects due to the random effects included in the model. Such variance may play a particularly important role in driving effects of object interest in learning. Indeed, the findings from the GCA are entirely in line with previous research on curiosity-driven approaches showing that a child's interest in an object helps them learn more about it and its properties (Begus et al., 2014; Partridge et al., 2015).

Importantly, we found that interest in the category and interest in the novel objects tested independently contribute to learning – the drop1 function revealed unique contributions of both these factors on learning, even when the other factors were included in the model. This is important, since without this control, it would be difficult to disentangle the contribution of these factors on a theoretical level alone. For instance, if children are interested in a particular object category, it is likely that they are more interested in an object that looks like a member of this category. Our findings suggest that category interest and object interest act as complimentary, but distinct forces that could potentially push a child's learning in different directions.

Indeed, a closer look at the different types of interest further reveals why the two factors may act independently of one another: Object interest, in the absence of any cues to the category this object belongs to, might be driven by the perceptual or visual salience of the novel object. Thus, if there were no perceptual cues pertaining to the category an object belongs to, object interest may be driven merely by the visual salience of a particular object, which may be more fluid in nature (as suggested by Figure 2.2E). Category interest, on the other hand, might be driven more by the similarity of a particular novel object to other members of the category a child is interested in, and the child's epistemic interest in these other category members. Object interest – in the absence of category cues – may, therefore drive the child to learn about specific objects in her environment, regardless of category membership, while category interest helps her add new members to a class of perceptually and/or conceptually similar objects.

While our findings support separable beneficial influences of category interest and object interest on word learning, the role of category size on word learning in the current study is less clear. Borovsky et al. (2016a) find a clear beneficial influence of category size on word learning: Children learn words more readily from semantically dense as opposed to sparse categories. While our results also hint at better learning from larger categories (see additional models in the supplementary analyses), the effect is not as robust as it is in the works of Borovsky et al. (2016a). One explanation for the less pronounced effect of category size in the current study might lie in differences in the design of the respective experiments. In contrast to Borovsky et al. (2016a), we exposed participants to familiar objects from the relevant categories prior to introducing them to novel objects from these categories. While this was methodologically necessary to measure their pupillary response to members of the category for our measure of category interest, the presentation of these familiar category members might attenuate the influence of category size. Furthermore, we note that our study controlled for category interest in examining the effect of category size (and vice versa), and found less robust evidence for the latter. Thus, it may be that the effects of category size reported in previous studies may be similarly attenuated by differences in category interest.

The findings of the current study help shed further light on previous studies examining the influence of category size on word learning (Borovsky et al., 2016a).

At 20 months of age, children already show considerable differences not only in the individual words they know, but also in the sizes of their semantic categories (Szagun et al., 2009). Why is it that some children know considerably more VEHICLE words than the average, while others pick up new ANIMAL words with ease? Borovsky et al. (2016a) highlight the influence of differently sized categories on learning, but do not examine the origins of these differences in category size. Our study suggests that one possible reason for such early differences in category size might be the child's interest in the category. If being curious about a natural category leads to better learning, the child will more readily learn novel members of this category, which leads to an increase in category size.

Note, however, that while parental interest ratings and pupillary interest measures similarly modulated learning, there was no correlation between parental interest ratings and the pupillary index of interest. Parental ratings, however, showed reduced variability with very few responses towards the lower end of the scale, potentially leading to the absence of a significant correlation, especially given the increased variability in the pupillary measure. It could also be argued that parents might be using their assumptions of category knowledge to judge their child's interest in a category or vice versa. Parental ratings of curiosity could, thus, be indicative of their child's past interests (reflected in their current category knowledge), while the pupillary measure may be tapping into developing interests. Ongoing studies in our laboratory with improved parental curiosity questionnaires are examining this issue further.

The distinction between a child's past and developing interests speaks to the possibility that the relation between category interest and category size is not unidirectional, but that there may be bidirectional forces at play: The child's interest in a category may only be triggered once the category reaches a certain size to begin with, which then leads to better learning of new category members and a further increase in category size. This idea links to Goldilocks theories of attention and curiosity-driven learning. For instance, Kidd et al. (2012, 2014) suggest that, in order to avoid wasting cognitive resources, infants allocate their auditory and visual attention to stimuli that are neither too simple nor too complex, which results in an inverted U-shape of attention allocation as a function of stimulus complexity. The same might hold true for category sizes and category interest: If the child is familiar with either very few or very many members of a category, they might not be as interested in it – either because they have no existing category exemplars to link the new members to or because they consider the category to be saturated. However, a category size that is "just right" might trigger their curiosity most, resulting in better learning. This is in keeping with Kang et al. (2009) who find that adults are most curious about an answer to a trivia question when their confidence in the answer is at a medium level, while curiosity is lower for answers they are not at all or very confident in.

On the other hand, it is clear that children can also learn from categories that they are less interested in: By 30 months, virtually all children master both Bagger ‚digger' and Bär ‚bear', despite the clear divide between Bagger babies (who know the word Bagger, but not Bär) and Bär babies (who know the word Bär but not Bagger) at 20 months outlined above. If children only learnt about the objects or categories they are curious about, they would be severely limited in their learning. While curiosity allows them to more readily learn about certain categories, overall learning would be narrowed if interest were the sole driving force behind word learning. This further raises questions about how children overcome their curiosity-driven bias to learn about all objects in their environment.

In conclusion, we present here evidence – based on two distinct measures of children's interest in different natural categories – that children learn words more easily when these words refer to the kinds of things they are interested in. Furthermore, supporting previous research, we show also that children learn words more easily when they are interested in the object this word refers to. These two factors, we have shown, make unique and separable contributions to word learning. Of interest is also the finding that parental curiosity reports manipulated word learning in a similar direction to the pupillary measure tested here, providing further support for pupillary change as an index of children's interest or arousal. On a final note, we stress that these findings do not downplay the importance of other factors that have previously been identified as influencing word learning, such as the input a child receives, or the number of words a child knows in a particular category. On the contrary, we believe that we can best describe word learning only if we take the multitude of these aspects as well as their interactions into account.

2.5 Appendix

Table 2.5: Parameter estimates, standard errors and p-values for model with different baseline, including category size, category interest and object interest.

	Estimate	Std. Error	t	p
(Intercept)	0.039	0.026	1.524	0.126
Linear time term	-0.017	0.114	-0.148	0.881
Quadratic time term	-0.007	0.067	-0.100	0.920
Cubic time term	-0.088	0.028	-3.151	0.002**
Category size	-0.043	0.032	-1.323	0.186
Category interest	0.103	0.029	3.591	<0.001***
Object interest	0.066	0.019	3.407	<0.001***
Category size on linear time term	0.219	0.158	1.380	0.168
Category size on quadratic time term	-0.091	0.089	-1.023	0.306
Category size on cubic time term	0.017	0.040	0.419	0.675

Chapter 3

Interest and novel word retention [1]

3.1 Introduction

Young children are curious learners who play an active role in exploring their surroundings and shape their learning environment according to their interests: studies show that Infants as young as 16 months use pointing gestures to request information about specific objects (Begus & Southgate, 2012) and also retain information better when it is provided at their request (Begus et al., 2014). For instance, 16-month-olds have been shown to imitate the functions of objects they chose to see the function of more robustly than those of objects they did not similarly choose (Begus et al., 2014), while pre-schoolers similarly show improved word-object learning when they can choose the order in which they a set of objects is labelled in an interactive word learning app (Partridge et al., 2015). This beneficial effect of active learning is sometimes explained by suggesting that having control over their learning experience may lead to richer encoding of episodic representations and sensorimotor associations in such active tasks, potentially due to the act of planning and making an active choice (see Markant, Ruggeri, Gureckis, & Xu, 2016, for a review). In keeping with the findings of such studies, active learning or curiosity-driven approaches have focused on whether children's curiosity or interest in a particular object may boost their learning more about this object.

However, interest may not be not limited to specific objects and may also apply at the level of object categories. Children as young as three and five-months of age have been shown to group objects into global-level categories, e.g., cats, dogs,

[1] This chapter was submitted to *Child Development* as Ackermann, L., Förster, M., Schaarschmidt, J., & Mani, N. The Role of Interest in Young Children's Retention of Words.

horses etc. (Eimas & Quinn, 1994; Eimas, Quinn, & Cowan, 1994). 7-month-olds also show global discrimination of categories such as animals and vehicles (Mandler & McDonough, 1993), even discriminating vehicles such as airplanes from perceptually similar objects like birds. Furthermore, children from around 18-months may show so called extremely intense interests in a category, to the extent that their parents are explicitly aware of and can report these interests (DeLoache et al., 2007; Johnson et al., 2004). These interests have further been shown to correlate with later levels of knowledge – with case studies showing that young children's fascination with and expertise related to dinosaurs and birds is consistent with their acquiring an extraordinary amount of information about these categories (Chi & Koeske, 1983; Mervis, Johnson, & Mervis, 1994). There are also suggestions that these interests may develop independent of external influences, given that parents report not giving explicit encouragement to the development of a particular interest, even finding their child's interests "odd" and the potentially perceptual origins of such interests, e.g., children interested in balls being interested in anything round from early on (DeLoache et al. (2007) ,but see Johnson et al., 2004, for a range of other factors that may influence sustainment of interests). Thus, this literature suggests that, from an early age, children may develop individual interests in certain categories of objects in their environment.

Given that children's interest in individual objects boosts their memory and retention of information about these objects (see Mani & Ackermann, 2018, for a more comprehensive review) and that children also develop global category-level interests, the current study examined the extent to which children's interest in particular categories boosts their learning and retention of novel labels for novel objects belonging to these categories.

A recent study examined this issue in some detail using a word-learning task with 30-month-old children and found that interest in the category a novel object belongs to as well as interest in the novel object itself independently contribute to children's successful recognition of newly learned novel word-object associations (Ackermann, Hepach, & Mani, 2020). In particular, this study found that children who were more interested in, for example, animals (as suggested by their pupillary arousal to images of familiar animals and parental reports of their child's interest in animals), were better able to recognise a newly learned animal name than a child who was less interested in animals.

While these results highlight the role of category interest on children's recognition of newly learned word-object associations, Ackermann et al. (2020) tested recognition immediately following exposure to the new word-object-associations. Their results cannot, therefore, speak to the extent to which children retained these learned associations later on. This distinction is important, since early word learning has been argued to operate on different time scales: Thus, the first step to learning a word is forming a not necessarily one-to-one mapping between words and their potential referents. At a second step, some of these mappings are pruned so that not all of these initial mappings eventually enter the lexicon and are retained as distinct word-object associations (Kucker et al., 2015; McMurray et al., 2012; Roembke & McMurray, 2016).

Fast mapping or disambiguation is assumed here to underlie initial mapping, where children infer which of two objects a recently introduced label is likely to refer to. Successful retention requires the child to both encode a word-object-association and later retrieve it from their long-term memory. Importantly, while the underlying processes of fast mapping and retention are interrelated, retention does not necessarily follow from fast mapping, and the two should not be conflated (Bion et al., 2013; McMurray et al., 2012). Kucker et al. (2015) differentiate here between the processes that allow a child to determine the referent of a word and the slower developmental processes that underlie learning and the accumulation of a network of associations from in-the-moment referent selection. How infants perform in a word recognition task immediately after exposure can tell us about factors that influence mapping words onto referents, with factors like novelty, salience and attention driving children's behaviour in the moment (Kucker et al., 2015). In contrast, children's performance in retention tasks gives us insight into processes and factors that operate on longer time scales, i.e., the processes that determine whether a fleeting, in-the-moment association is retained and recalled over a longer period of time.

Evidence for retention in laboratory word learning tasks is mixed. Horst and Samuelson (2008) find that 24-month-old children can fast map novel words onto novel objects in a referent selection task, but do not retain these newly formed word-object-associations after even a five-minute delay. Similarly, Bion et al. (2013)

highlight the importance of different time scales by distinguishing fast mapping from slow learning. They tested children aged 18, 24 and 30 months on their disambiguation skills - the ability to fast map a novel word onto a new referent - and their subsequent retention of the novel word. Bion et al. (2013) find that 24-month-olds reliably fast map novel words onto their referents, but show no evidence of retention of the newly-learnt word-object-associations and it is not until 30 months that children retain the newly-learnt word-object-associations. It should be noted that other studies find evidence for retention at much younger ages: In an ERP study, Friedrich and Friederici (2011) show that children as young as 6 months not only successfully encode word-object-mappings, but also show weak familiarity effects for those word-object-associations 24 hours after exposure. Using an offline multiple choice task, Woodward, Markman, and Fitzsimmons (1994) find that children aged 13 and 18 months show retention of newly-learnt word-object-associations after a 24 hour delay (see also Childers & Tomasello, 2002).

Competition between concurrently presented associations and, relatedly, the salience of particular associations play critical roles in whether a newly learned association is retained and recalled. For instance, in the Horst and Samuelson (2008) study, children showed weak evidence of retention of a learned association once the salience of the target object was increased relative to the distractors. Salience here was increased by adding more naming events and visually separating the novel target object while labelling (see also Axelsson, Churchley, & Horst, 2012). The authors argue that competition plays a key role in bridging the gap between referent selection and later retention: Within a trial, competition between the target and distractors hinders successful encoding of the new word. When competition was reduced by singling out the target object, children were able to retain the novel word-object-association (but see Zosh, Brinster, & Halberda, 2013). Thus, there may well be continuity between the influence of salience on real-time referent selection and later integration of learned information into a network of associations. In particular, slow learning is characterised by integration into a network of associations, and the strength of particular associations, which may be influenced by the salience of these associations, may modulate such integration (Kucker et al., 2015). Indeed, this continuity is attested to by the finding in Bion et al. (2013) that children who perform better on the disambiguation trials also show better retention of the novel words.

As Horst and Samuelson (2008) note, heightened salience of the target object decreases competition, paving the way for successful retention at 24 months. Horst and Samuelson (2008) increased salience by singling out the object and repeating the label more often - thus, salience was not dependent on the object itself, but on the way the experimenters presented children with information about an object. However, it has also been shown that interest in an object (Begus et al., 2014) or the category the object belongs to (Ackermann et al., 2020) helps children learn about more about it and its properties. It could, therefore, be argued that the individual interests a child brings to the table could intrinsically increase the salience of objects, which, in turn, might lead to better retention. Against this background and in keeping with recent approaches to learning that place the child in a more active role, the current study explores the possibility that children's individual interests can – similar to the experimental manipulation of object salience in Horst and Samuelson (2008) – serve to increase the salience, and thereby, mapping and retention of a newly learned word-object association.

3.1.1 The current study

The current study examines whether a child's interest in a natural category, e.g. animals, influences their mapping and retention of a newly learned word-object association from this category. We hypothesize that interest in the category the object belongs to, henceforth, *category interest*, boosts retention by intrinsically increasing the salience of objects from high interest categories. If that is indeed the case, children should show better learning and retention for words from high-interest categories as opposed to low-interest categories. Given that interest in a particular object has been linked to better learning outcomes (Ackermann et al., 2020; Begus et al., 2014), we are also interested in the effect of *object interest* on learning and retention. Furthermore, as increased interest in a category in the past might lead to children knowing more words in this category at the time of test and this knowledge may also impact learning and retention of the word-object associations, we controlled for individual differences in *category size* in examining the effect of category and object interest on retention.

In the current study, we examine recognition (immediately after exposure to the new word-object association, as in Ackermann et al. (2020)) and retention and recall of word-object association after 5 minutes (in line with the delay chosen by Horst and Samuelson (2008)) and 24 hours (in line with the delay chosen by Friedrich and Friederici (2011) and Woodward et al. (1994)) in children aged 24 and 38 months. In keeping with the results of Horst and Samuelson (2008), we expect the younger age group to show retention only for objects from high interest categories. Older children should show retention regardless of the salience of the target object (Bion et al., 2013), but if category interest has a beneficial influence even at this later age, we expect them to show stronger retention for objects from high-interest categories.

As in Ackermann et al. (2020), we had two measures of category interest. The first was a measure of children's pupillary arousal to images of familiar objects from the different categories we presented. As in Ackermann et al. (2020), we took the averaged pupillary arousal (averaged across multiple familiar members of a particular category) as an index of children's arousal upon being presented with members of this category, and, by extension, a measure of children's interest in the category to which each novel object belongs. This is in keeping with adult studies showing a correlation between adults' self-reported curiosity in the answer to a question and their pupillary arousal prior to and upon being given this answer (Kang et al., 2009). The second measure of interest was parental reports of their child's familiarity with and curiosity in objects from particular categories. Both measures of category interest independently predicted children's recognition of newly learned word-object associations in Ackermann et al. (2020) and were, therefore, included as measures of category interest in the current study.

The eye-tracking part of study consisted of five phases, the first three of which, a *category arousal* phase, a *word learning* phase, a *word recognition* phase, correspond to the design of Ackermann et al. (2020). Please note that we opt for the term category arousal rather than category interest when referring to the pupillary measure, as pupil dilation itself primarily reflects stimulus-induced arousal related to a number of underlying cognitive states (cf. Hepach & Westermann, 2016, for an overview), including, but not limited to, interest. In addition, we further included two retention phases, the first of which was 5 minutes after exposure to the novel word-object associations and the second of which was 24 hours later. In the *category arousal* phase, children saw a total of 16 familiar objects from four early-acquired semantic categories (i.e., four objects per category) and heard their labels. We measured their pupil dilation following presentation of the image and label as an index of how aroused they were by the object, and by extension across all images from a category. The pupillary measure, averaged across all four category members, thereby gave us an individual measure of children's state of arousal following exposure to familiar objects from a category, i.e., their *category interest*. In addition, parents were asked to rate their child's curiosity towards and familiarity with the objects and categories presented, as a separate measure of children's interest in the categories. In the *word learning* phase, children saw one novel object from each of the four categories and heard the corresponding label 10 times. Again, pupil dilation in response to the novel object was measured as an index of children's state of arousal following exposure to this object, giving us a measure of *object arousal*. In the word recognition phase, children saw two novel objects side by side and heard the label of one of the objects, to test their recognition of the newly learned word-object associations using the intermodal preferential looking paradigm (IPLP, Golinkoff et al. (1987)). In this paradigm, increased fixations towards the target relative to the distractor in response to an auditory prompt indexes successful recognition. The same paradigm is repeated in the two *retention* phases, with the first *retention* phase taking place after a 5-minute play break and the second *retention* phase taking place the next day.

3.2 Methods

3.2.1 Participants

For the younger age group, 52 children aged 24 months (M = 23 months 29 days, SD = 38.0 d, range 22 m 0 d – 26 m 6 d, 19 female) were recruited from a Northern German university town through the institute's database. Eight children were excluded prior to pre-processing due to not completing even one test phase (n = 8). Of the remaining 44 children, 33 children provided data for all phases. Altogether, 42 children provided data for the t1 (immediately after learning), 40 children provided data for t2 (five minutes later) and 39 children provided data for t3 (24 hours later).

For the older age group, we recruited 50 children aged 38 months (M = 37 m 7 d, SD = 34.0 d, range 35 m 28 d – 39 m 24 d, 22 female). Six children were excluded prior to data analysis due to having been born more than 6 weeks prematurely (n=3) or due to their not providing data for critical parts of the experiment (n=3, 1 did not complete any of the test phases, 2 did not provide data for either category arousal or object arousal phases). Of the remaining 44 children, all children provided data for t1 (immediately after learning), 42 provided data for t2 (five minutes later) and 43 provided data for t3 (24 hours later). All children were born full-term, had normal hearing and vision and were reported to be monolingual learners of German. 88.6 % of parents (n=79) had a high school diploma and 75 % (n=66) had completed a university degree. Please note that data on race or ethnicity is not commonly collected in Germany and can therefore not be reported. In return for their participation in the study, children received a certificate after the first session and a book after the second. Data was collected between December 2018 and August 2019. The study was reviewed and approved by the ethics committee of the Institute of Psychology, University of Göttingen.

3.2.2 Stimuli

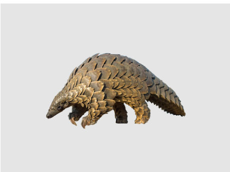
We chose the same visual and auditory stimuli as in Ackermann et al. (2020). In particular, we chose four familiar objects from four early-acquired semantic categories: animals, vehicles, drinks, and clothes. These sixteen objects were chosen to serve as familiar objects during the *category interest*, word recognition and retention phases. All familiar objects are reported to be known to more than 50 % of German-learning 30-months-olds (Szagun et al., 2009, see Table 3.1 for an overview of the percentage of participants in this study who were reported to know each word).

In addition, we chose one rare member from each category to serve as a novel object whose label children would be introduced to during the experiment (see Table 3.2 for all novel objects). All novel objects were perceptually similar to typical category exemplars, strongly suggesting category membership. None of the labels referring to those objects appeared in the German CHILDES corpora (CLAN, MacWhinney (2014)), confirming their low frequency in children's everyday linguistic environment. All labels referring to the novel objects (Pango, Malpe, Rikscha and Gugel)

Table 3.1: Percentage of children in each age group reported to know (defined as *understands* or *understands/says* on the FRAKIS) each word.

Category	Object	Known % (24 months)	Known % (38 months)
Animals	Ant	68.2	97.7
	Crocodile	79.5	100
	Mouse	90.9	100
	Penguin	70.5	100
Vehicle	Bus	97.7	100
	Helicopter	90.9	100
	Tractor	95.4	100
	Tricycle	72.7	93.0
Drinks	Beer	63.6	83.7
	Coffee	84.1	97.7
	Milk	95.4	100
	Water	97.7	100
Clothes	Diaper	93.2	100
	Pajamas	95.4	100
	Scarf	77.2	100
	Trousers/pants	93.2	97.7

Table 3.2: The four novel objects and their labels.

Animals	Clothes	Vehicles	Drinks
broad		narrow	
Pango	Gugel	Rikscha	Malpe
			

were bisyllabic and conformed to German phonotactic rules.

A photorealistic image of each familiar and novel object against a light grey background measuring 360 x 360 px was created. In the *category interest* and *word learning* phases, we used a scrambled version of each picture to serve as the baseline for the pupillary measure, thereby controlling for differences in luminance across objects. For scrambling, pictures were broken up into 100 squares of 40 x 40 px that were then rearranged randomly using the Scramble Filter plugin for Adobe Photoshop.

All auditory stimuli were recorded by a female native speaker of German in an enthusiastic, infant-directed voice at a sampling rate of 44,100 Hz. Auditory stimuli were filtered for environmental noise using Goldwave. In the *category interest* phase, speech stimuli consisted of the object label preceded by the definite article (der, die or das). In the *word learning* phase, the novel label was embedded into a passage containing five different carrier sentences with a total length of 12.5s per passage: Schau mal, eine [target]! Das ist eine [target]! Siehst du die [target]? Da ist eine [target]! Wow, eine [target]! (”Look, a [target]! This is a [target]! Do you see the [target]? There is a [target]! Wow, this is a [target]!”). In the word recognition and retention phases, children were prompted to look at the target with one of two carrier sentences: Siehst du den/die/das [target]? or Wo ist der/die/ das [target]? (”Do you see the [target]?” or “Where is the [target]?”), with the onset of the target word 1,020 ms into the test phase of the trial.

3.2.3 Parental questionnaires and additional tests

Parents were asked to fill out a shortened version of the FRAKIS (Szagun et al. (2009), the German adaptation of the MBCDI) that only included words from the categories used in the study. We also asked parents to list all other words their children knew in the respective categories. Additionally, parents were asked to rate their child’s curiosity towards and interest in the familiar objects and categories used in the study using a 7-point Likert scale. These questionnaires were mailed to the families before their laboratory appointment. Additionally, overall vocabulary size for children in the younger age group was estimated using the BabyLex app (Mayor & Mani, 2019), a 25-word-version of the FRAKIS. Children in the older age group also completed the SETK 3-5 (Grimm, 2015), a developmental language test aimed at children aged 3;0 through 5;11, consisting of four subtests. However, we did not include these measures in the models reported here as not all children completed the additional tests, which would reduce the number of observational units and thereby make the model estimates less reliable (Meteyard & Davies, 2020).

3.2.4 Procedure

We used a Tobii X 120 eye tracker with a gaze sampling rate of 120 Hz and a pupil diameter sampling rate of 40 Hz to record eye movements. During the experiment, participants were seated either in a car seat or on their caregiver’s lap approximately

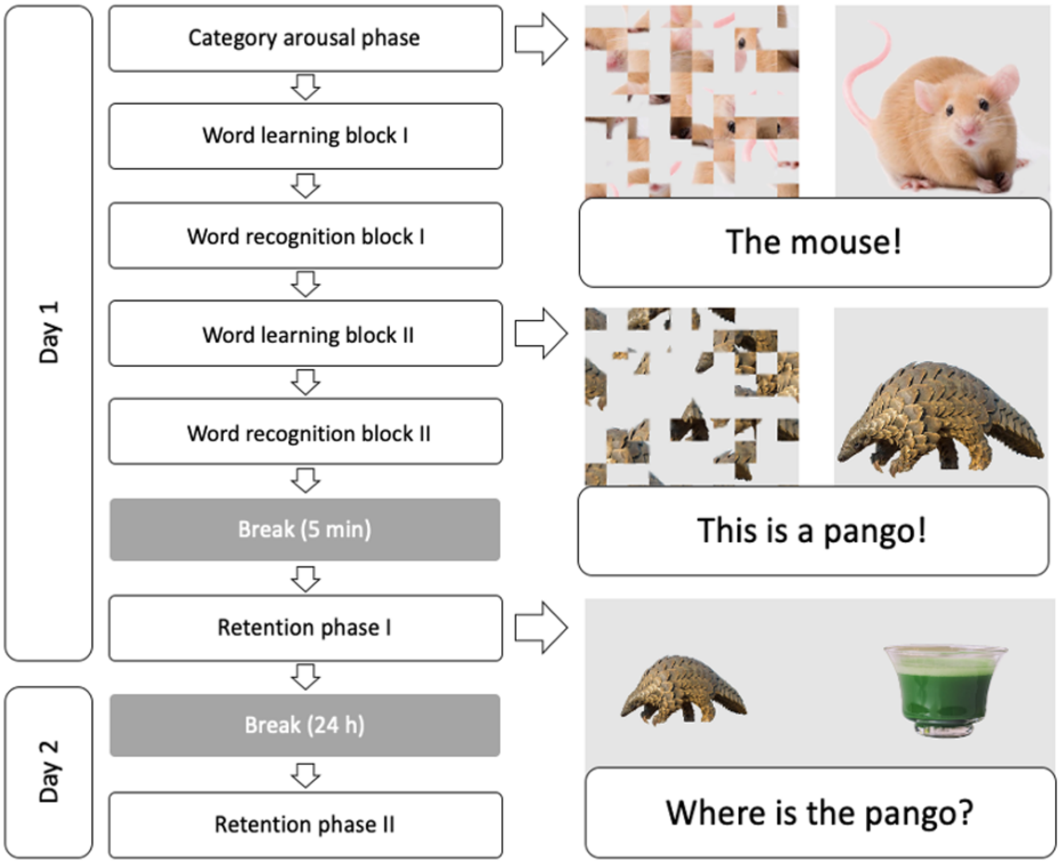


Figure 3.1: Overview of the study phases with example stimuli for the category arousal phase, word learning phase and word recognition / retention phase.

60 cm away from a 40-inch screen on which stimuli were displayed using Tobii Pro Studio (version 3.4).

The study was divided into two sessions which took place on two consecutive days (cf. Figure 3.1). During the first session, children were first exposed to 16 familiar objects from the four categories (see Table 3.1) while their pupil dilation following unscrambling of the images of the familiar objects was measured (*category interest* phase). The familiar objects were presented in blocks of two, with each block containing two objects from the same category (e.g. a tractor and a bus). The order of blocks was counterbalanced across children. In each trial, children first saw a scrambled version of the picture for 2000 ms before the unscrambled picture appeared for 3000 ms. The label of the familiar image was presented 1000 ms into the unscrambled phase.

The *word learning* phase was split into two blocks. In each block, children were presented with two of the four novel objects and their labels. Children were presented with two learning trials for each novel object, resulting in four learning trials per block. In each learning trial, children first saw a scrambled version of the novel object for 2000 ms before the unscrambled image was shown for 12.5 s. The object was labelled five times per trial, with the label embedded in five different carrier sentences. During each learning trial, only one object was present on screen. In the second learning block, children saw the remaining two novel objects. The pairing of objects and order of blocks was counterbalanced across children.

The word recognition phase (henceforth, t1) also consisted of two blocks. The first block immediately followed the first learning block, while the second word recognition block followed the second learning block. Each word recognition block consisted of eight trials, with alternating novel and familiar word recognition trials. In each word recognition trial, two objects were shown side-by-side with 300 px separating the two images. The images were first shown in silence for 3000 ms before a colorful center stimulus appeared. Once the child fixated on the center stimulus, the two images reappeared and the child was prompted to look at the target object, with the onset of the target word being played 1,020 ms after the reappearance of the images. After the onset of the target word, the pictures remained on screen for 2,500 ms, resulting in a total length of 3,520 ms for the critical period of the trial. In the novel test trials, the two previously seen novel objects were presented together. Across all four test trials, both novel objects served twice as the target and twice as the distractor. In the familiar trials, two objects from the object presentation phase were paired in a way that the objects came from two different categories. This first part of the eyetracking experiment lasted approx. 7 minutes.

Afterwards, the children left the experimental booth to play with building blocks for five minutes. Parents were instructed not to name or talk about the novel objects during this break.

The first retention phase (henceforth, t2) consisted of 16 trials, with novel and familiar trials alternating as in the word recognition phase. In the retention phase, objects were yoked together as in in the word recognition phase, albeit in a different order. The retention phase lasted approximately three minutes. Children returned the next day for the second retention phase (henceforth, t3), which followed the structure of the first retention phase, but presented the same 16 trials in a different order. On the second day, the older children also completed the SETK 3-5 (Grimm, 2015), which took between 15 and 25 minutes. The caregivers of the younger children completed the Babylex questionnaire (Mayor & Mani, 2019) which estimated their child's overall vocabulary size.

3.2.5 Preprocessing

For each time point where we had pupillary data, the size of the left and right pupils were exported from only those time bins which were part of a fixation (determined automatically by the eyetracker) and had valid eyetracking data. Pupil data were then filtered using a threshold filter and missing data points were interpolated with a sample size of 4 (separately for both eyes, see Ackermann et al., 2020 for further details of filtering and interpolation). Pupil data was then averaged across both eyes when data were available for both eyes or the eye providing data. To calculate pupillary arousal during the *category arousal* phase, the last 500 ms of the scrambled phase served as the baseline, while the entire 3000 ms of the unscrambled phase served as the window of interest. We calculated pupillary arousal separately for each image in each category and then calculated category arousal as the average pupillary arousal across all members of the category. We ensured that we had pupillary data for at least two members of each category in order for the data to be included in the analyses. This led to a loss of 16 datapoints in the dataset. To calculate pupillary arousal during the object arousal phase (word learning phase), we took the last 500 ms of the scrambled image as the baseline, while the window between 500 ms after onset of the unscrambled window and the onset of the label was used for analyses. Note that the analyses were also repeated with different baseline and critical windows and revealed a very similar pattern of results.

We were also interested in the effect of the number of words known in each semantic category (*category size*) on recognition and retention. Since only relative category size yielded an influence of category size on word learning in Ackermann et al. (2020), *category size* was calculated as the relative size of the categories each child was reported to know in each of the four categories.

Finally, we examined parental reports on how curious and how familiar their children were in objects from the four categories tested. The parental data was heavily skewed with most parents reporting their children to be both highly familiar with and curious about the objects from the four categories and log-transforming the data did not help. The analyses using this data should, therefore, be treated with caution.

3.3 Results

We set out to examine the influence of interest in natural categories as indexed by – pupillary arousal following exposure to members of the semantic category the novel object belongs to (*category interest*), parental ratings of children's curiosity in the category the object belongs to (curiosity), and parental ratings of children's familiarity with the category the object belongs to (familiarity) – on children's novel word recognition and retention.

First, for each individual child we assigned categories to high or low category arousal based on the median split of that child's pupillary arousal to familiar members of these categories in the category arousal phase. One-sample t-tests then examined whether children fixated the target more than chance separately for objects from high arousal and low arousal categories. This was done separately for each time-point, i.e., immediately after learning, 5 minutes later and 24 hours later. In addition, a more fine-grained analyses allowing us to capture greater variation in category arousal included simple correlations between category arousal and parental curiosity and familiarity measures with the proportion of target looking at each test phase.

Finally, to examine the influence of individual predictors while controlling for other predictors, we fitted a linear mixed effects model (LMM) for each age group at each timepoint (t1 immediately after exposure, t2 five minutes after exposure, and t3 24 hours after exposure) using lme4's lmer function in R (D. Bates et al., 2015). An effect of *relative category size*, *category interest* and *object arousal* were included as fixed effects in each model. In addition, participant and category were included as random effects, allowing for random intercepts across observational units. All predictors were centered, resulting in the following model for each time point:

Baseline corrected PTL c.(rel.size) + c.(category arousal) + c.(object arousal) + (1 | id) + (1 | category)

Details of the model estimates are summarized in Table 3 for the younger age group and Table 5 for the older age group.

Additionally, we fitted a similar model that included parental ratings of their child's familiarity with and curiosity for the different categories as well as category arousal and relative category size as fixed effects. We removed object arousal from this model due to reduced data of object arousal and problems running the drop1 analyses reported in this model. Parents were asked to rate curiosity and familiarity on a 7-point Likert scale (1 = not familiar/curious at all, 7 = very familiar/curious). We fitted this model separately due to the skewed nature of the parental data and highlight caution in interpretation of these models. This resulted in the following model:

Baseline corrected PTL c.(rel.size) + c.(curiosity) + c.(familiarity) + (1 | id) + (1 | category)

Details of the model estimates are summarized in Table 4 for the younger age group and Table 6 for the older age group. All models reported were checked for and variance inflation using the mer-utils package and deviations from acceptable norms are reported.

Data are plotted both aggregated across the entire time course of the trial as well as depicting children's fixations throughout the trial. Note that in order to plot the time-course graphs, the data were arbitrarily split into groups based on a median-split of the significant predictors measures while the data entered into the model were continuous. Thus, the time-course graphs do not depict the model results as accurately as the additionally reported scatter plots between the significant predictors and the proportion of target looking. Nevertheless, we report the time-course graphs for an estimate of the unfolding of children's responses across the trial.

3.3.1 24-months-olds

Children showed recognition of the target from high arousal categories at t1, $t(38)=2.92$, $p=.005$, 95% CI: .023, .127, and at t2, $t(41)=2.24$, $p=.031$, 95% CI: .007, .154, but not at

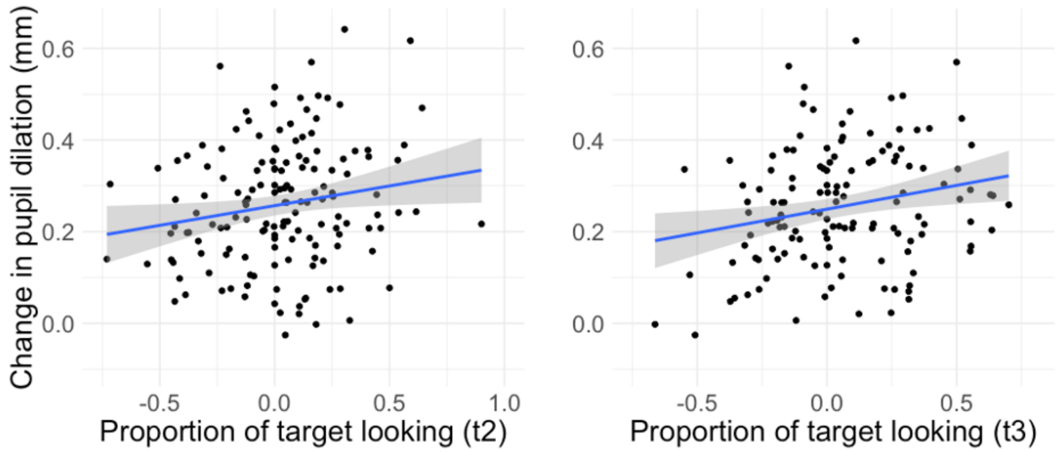


Figure 3.2: Scatterplot of the correlations between proportion of target looking (at t2 and t3) and change in pupil dilation.

t3, t(35)=1.53, p=.134, 95% CI: -.021, .154. There was no evidence of children recognising targets from low arousal categories at any time-points (p >.2). This suggests that children readily learn and recognise words from high arousal categories both immediately after exposure to the novel word-object mappings and when tested after a five-minute gap, but not when tested 24 hours later. They show no similar evidence of recognising words from low arousal categories at any time-point.

Simple correlations revealed a significant correlation between category arousal and the proportion of target looking at t2 (5 minutes later; r=.18, p=.029) and t3 (24-hours later; r=.22, p=.009), but not at t1 (p>.5). Scatter plots depicting these correlations are plotted in Figure 3.2.

Models including relative category size, category arousal and object arousal as predictors yielded a significant effect of category arousal at t3, β = 0.532, t = 2.617, p = 0.008, and no other significant effects (see Table 3.3). This is corroborated by the correlations reported above. Contrary to the t-tests reported above, but in keeping with the correlations, we found that, when controlling for category size and object arousal, after a 24-hour-delay, children more readily recognize words from categories whose objects they showed increased pupillary arousal to relative to categories whose objects they showed reduced pupillary arousal to.

For further visualisation of this effect, we performed a median split on the pupillary measure, separating trials into high category arousal and low category arousal trials and plotting the time-course of target fixations (Figure 3.3).

Table 3.3: Parameter estimates, standard error and p-values for model including category size, category arousal and object arousal at all three time points (t1 = immediately after exposure, t2 = after five minutes, t3 = after 24 hours) for the younger age group.

Predictor	t1			t2			t3		
	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
(Intercept)	.039	.034	.251	.015	.032	.632	.038	.028	.175
Category Arousal	-.034	.141	.808	.202	.183	.269	**.532**	**.203**	**.008**
Object Arousal	.044	.112	.692	-.006	.144	.964	-.016	.144	.911
Category Size	-.0005	0.001	.532	-.002	.001	.072	-.001	.001	.263

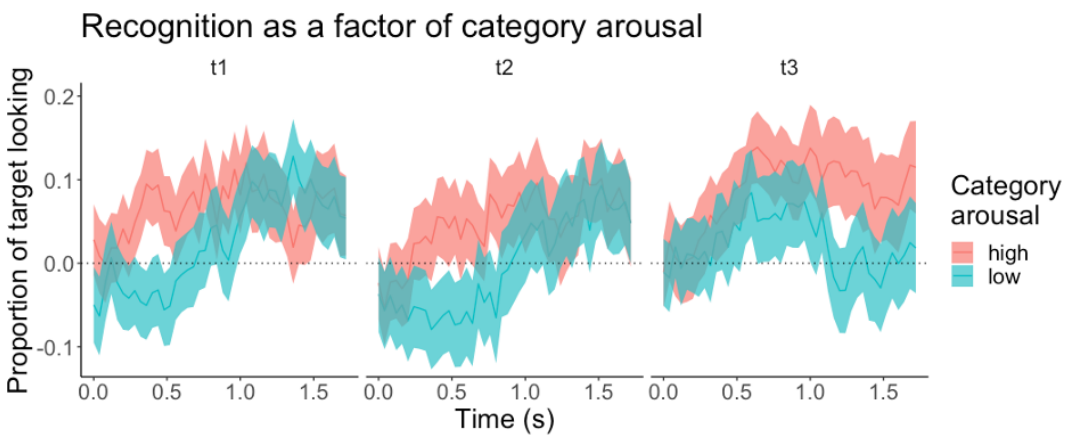


Figure 3.3: Time course of target recognition in each of the three test phases for 24-months-olds, split by high and low category arousal. The dotted line indicates chance.

Table 3.4: Parameter estimates, confidence intervals and p-values for model including parent-rated curiosity, parent-rated familiarity, category arousal and category size at all three time points (t1 = immediately after exposure, t2 = after five minutes, t3 = after 24 hours) for the younger age group.

Predictor	t1			t2			t3		
	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
(Intercept)	.042	.024	.076	.017	.022	.439	**.055**	**.026**	**.035**
Curiosity	<0.001	.011	.977	-.011	.012	.345	-.024	.016	.140
Familiarity	.005	.017	.748	-.017	.02	.374	**.068**	**.023**	**0.002**
Category arousal	.034	.139	.806	**.384**	**.162**	**.017**	**.443**	**0.192**	**0.021**
Category size	<0.001	.001	.527	-.001	<.0001	.291	<.001	0.001	0.540

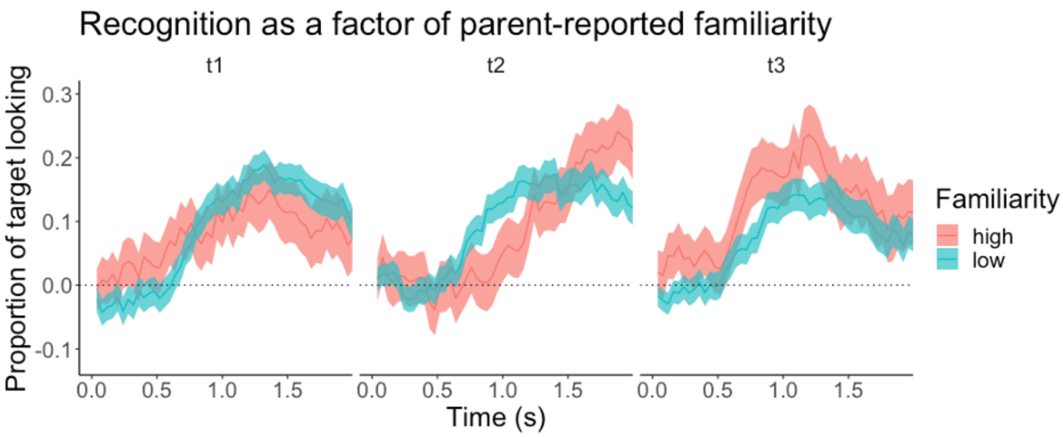


Figure 3.4: Time course of target recognition in each of the three test phases for 24-months-olds, split by parent-rated familiarity. The dotted line indicates chance.

Next, we examined the models including relative category size, category arousal, curiosity and familiarity as predictors. These yielded a significant effect of category arousal at t2, $\beta = 0.384$, t = 2.38, p = 0.017, and t3, $\beta = 0.443$, t = 2.31, p = 0.021, as well as a significant intercept, $\beta = 0.055$, t = 2.107, p = .035, and significant effect of familiarity at t3, $\beta = 0.068$, t = 3.003, p = .002 (see Table 3.4 and Figure 3.4). Given effects of both familiarity and category arousal at t3, we ran a drop1 analyses at t3 to examine the independent contributions of these predictors and found that both category arousal, = 5.21, p =.022, and familiarity, = 8.70, p=.003, contributed independently to model fit. We remind the reader, however, that parental ratings were heavily skewed (even when log-transformed) and urge caution with interpretation of these models.

Parental ratings of curiosity (r = 0.227, p = 0.012) and familiarity (r = 0.333, p < 0.001) were positively correlated with parent-reported category sizes. However, we found no significant correlations between parental ratings and category arousal

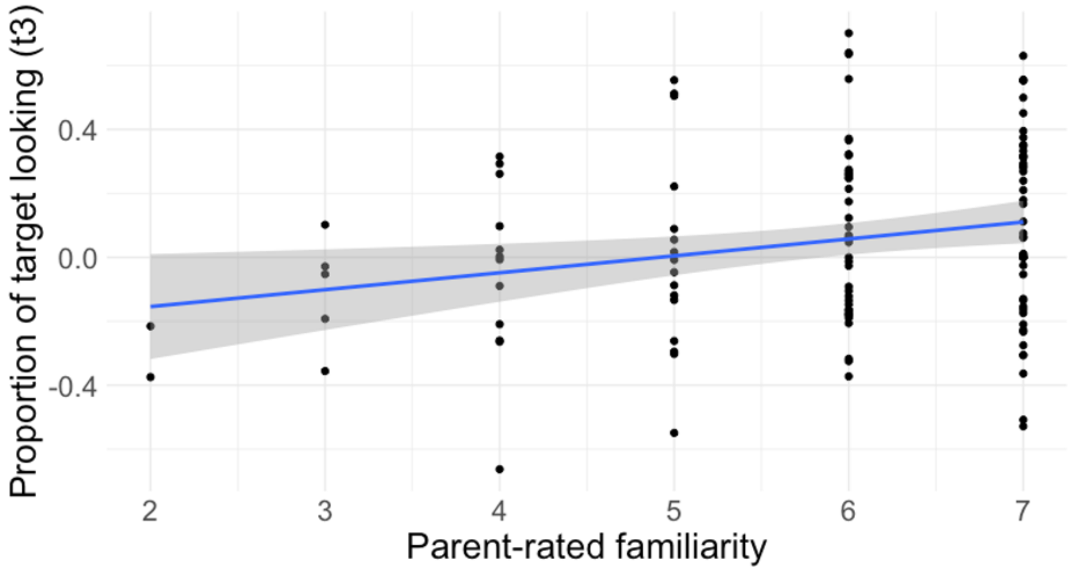


Figure 3.5: Scatterplot of the correlations between parent-rated category familiarity and PTL at t3.

as indexed by the pupillary measure (all $p > 0.05$). At t3, target looking was positively correlated with parent-rated familiarity (Kendall's tau = 0.164, p = 0.040, see Figure 3.5).

3.3.2 38-months-olds

Children showed recognition of the target from low arousal categories at t1, t(41)=2.63, p=.011, 95% CI: .017, .126, and recognition of high arousal categories at t2, t(35)=3.99, p<.001, 95% CI: .059, .181, and at t3, t(37)=3.27, p=.002, 95% CI: .040, .171. There was no evidence of children recognising targets from low arousal categories at t2 or t3 (p >.1). Children retained word mappings of objects from high arousal – but not low arousal – categories at t2 and t3. Curiously, they showed the opposite pattern of results at t1.

Simple correlations revealed a significant correlation between category arousal and the proportion of target looking at t2 (5 minutes later; r=.201, p=.014). Note that visual inspection of the scatter plots revealed some outliers in the data, so we re-ran the correlation excluding data points that were more than two standard deviations from the mean. A similar correlation between category arousal and the proportion of target looking was found at t2 with this reduced dataset, r=.22, p=.012. Scatter plots depicting these correlations are plotted in Figure 3.6.

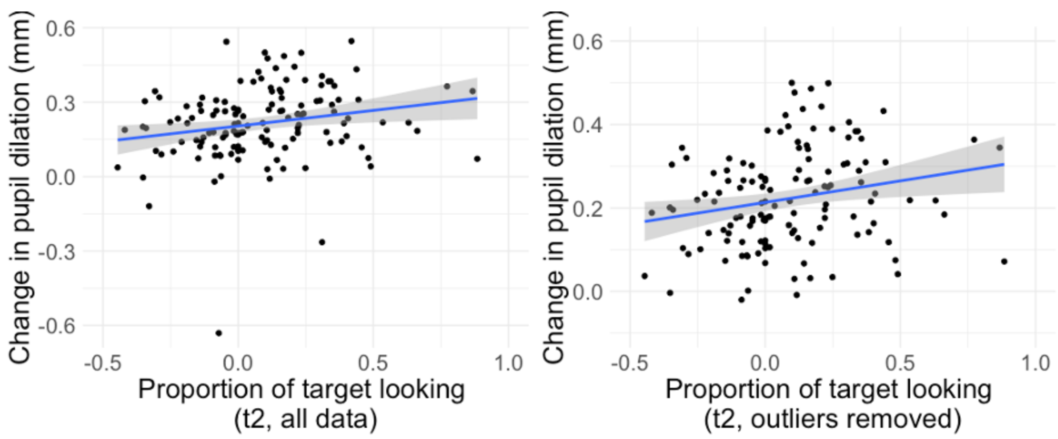


Figure 3.6: Scatterplot of correlation between PTL at t2 and category arousal, for the full dataset (left) and the reduced dataset (right).

Table 3.5: Parameter estimates, confidence intervals and p-values for model including category size, category arousal and object arousal at all three time points (t1 = immediately after exposure, t2 = after five minutes, t3 = after 24 hours) for the older age group.

Predictor	t1			t2			t3		
	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
(Intercept)	**.054**	**.023**	**.023**	**.092**	**.022**	**<.001**	**.072**	**.025**	**.004**
Category Arousal	.119	.141	.403	**.336**	**.149**	**.024**	.220	.164	.178
Object Arousal	.058	.104	.577	.222	.114	.051	.126	.117	.281
Category Size	.003	.005	.455	.003	.005	.451	<.001	.005	.941

Models including relative category size, category arousal and object arousal as predictors yielded a significant effect of category arousal at t2, $\beta = 0.336$, $t = 2.26$, $p = 0.024$ and significant intercepts at all three time-points (see Table 3.5). This is corroborated by the correlations reported above. While children showed robust recognition of the newly-learned words at all three time-points tested, after a 5 minute delay, children more readily recognize words from categories whose objects they showed increased pupillary arousal to relative to categories whose objects they showed reduced pupillary arousal to.

For visualisation of this effect, we performed a median split on the pupillary measure, separating trials into high category arousal and low category arousal trials and plotting the time course of target fixations (Figure 3.7), which suggests above-chance target looking for words from high-arousal categories at t3. Note that the data for category arousal entered into the model are continuous and the data visualised in Figure 3.7 are based on an arbitrary split of the categories into high and low arousal

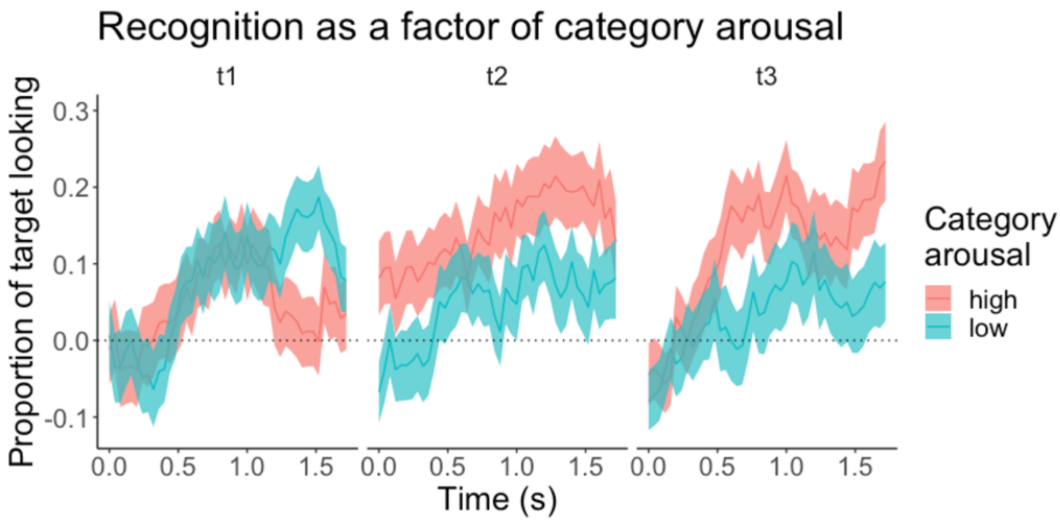


Figure 3.7: Time course of target recognition in each of the three test phases for 38-months-olds, split by high and low category arousal. The dotted line indicates chance.

categories. Therefore these data do not capture the model as well as the scatter plot depicted in Figure 3.6.

Next, we examined the models including relative category size, category arousal, curiosity and familiarity as predictors. These yielded only significant intercepts at all three time-points and no effects of any of the predictors (see Table 3.6 for further details). Children showed recognition of the newly learned words at all time points, but we did not find evidence for an influence of category interests based on either parental reports or category arousal when controlling for the other measures on responding in the older age-group. We note, however, that as with the younger age-group, the parental responses were heavily skewed and urge caution with interpretation of these results.

Finally, we note that, in 38-months-olds, category size was positively correlated with parent-reported familiarity (Pearson's $r = 0.409$, $p < 0.001$), but not with parent-rated curiosity (Pearson's $r = 0.139$, $p = 0.117$). We also found no significant correlations between parental ratings and the pupillary arousal measure (all $p > 0.05$).

3.4 Discussion

There is recent renewed interest in the extent to the child is a critical source of variability in learning outcomes and developmental trajectories: studies suggest that

Table 3.6: Parameter estimates, confidence intervals and p-values for model including parent-rated curiosity, parent-rated familiarity, category arousal and category size at all three time points (t1 = immediately after exposure, t2 = after five minutes, t3 = after 24 hours) for the older age group.

Predictor	t1			t2			t3		
	Estimate	SE	p	Estimate	SE	p	Estimate	SE	p
(Intercept)	**.056**	**.024**	**.022**	**.083**	**.023**	**<.001**	**.064**	**.032**	**.044**
Curiosity	-.021	.011	.071	-.013	.014	.307	.012	.015	.431
Familiarity	.030	.026	.849	.003	.028	.928	-.003	.031	.923
Category arousal	.077	.144	.237	.299	.159	.061	.206	.174	.235
Category size	<.001	.005	.849	.039	.005	.446	.001	.006	.774

children shape their own learning environments by preferentially attending to stimuli they are interested in and learn best when information is provided at their own request (Begus et al., 2014; Begus & Southgate, 2012; Partridge et al., 2015). While such studies have typically investigated the extent to which children's interest in individual objects shape their acquisition of information about these objects, Ackermann et al. (2020) showed that this also extends to interest in a natural category in a word-learning task: 30-month-olds showed more robust recognition of newly-learnt word-object-associations when the objects belonged to categories that the child was interested in. This intuitive finding speaks to research on extremely intense interests in young children showing that children demonstrate remarkable knowledge about categories they are interested in (DeLoache et al., 2007).

Thus far, studies on the role of interest have only examined children's recognition of newly learned word-object mappings immediately after they were exposed to the novel mappings (Ackermann et al., 2020). On the one hand, studies on children's EIIs speak to the possibility of children's acquisition and long-term retention of information they are interested in, suggesting that children may also retain information they are interested in, here, novel word-object mappings from high interest categories, longer. On the other hand, word learning is a complex process operating on multiple time scales, such that successful recognition or disambiguation of newly learned word-object mappings may not imply successful long-term retention and recall of these initial mappings (Bion et al., 2013; Horst & Samuelson, 2008). While the two concepts, also known as fast mapping and slow learning, are related to one another, they ought not to be conflated (Bion et al., 2013). Furthermore, it has been suggested that children's performance in recognition and retention tasks provides insight into the different processes at play at the different timescales. In particular, previous research has highlighted the importance of input salience in novel-word retention, with 24-month-olds showing successful retention of salient newly learned word-object associations (Horst & Samuelson, 2008).

Against this background, the present study examined whether interest in a natural category, as indexed by either children's pupillary arousal upon being exposed to familiar objects from different categories and parental reports of their child's interest and familiarity in those categories, serves a similar function (to salience) in their retention of newly learned word associations for objects from these categories: Were such interest in objects from a category to boost the salience of a novel object from the same category, children should show more robust mapping and retention of words from high-interest categories relative to low-interest categories.

While the results from the different analyses reported above are mixed, taken together, our study yields three main findings: First, we found considerable evidence suggesting that interest in the category – as indexed by pupillary arousal to familiar objects from this category – modulates young children's recognition and retention of newly-learned word-object associations from high-arousal categories. Second, we interpret the results as providing evidence for modulation of word-object recognition and retention by interest in the younger age-group and robust evidence for retention of learned word-object associations only at the older age-group (cf. Bion et al., 2013), Third, we found limited evidence for parental ratings of children's curiosity modulating children's word-object learning and retention. This stands in contrast both to the effects reported in Ackermann et al. (2020) and the effects of category interest – as indicated by the pupillary arousal measure reported here (and in Ackermann et al., 2020), highlighting the need for a discussion of the concept(s) of interest. We discuss these findings in more detail below.

First, we discuss the results with the younger age-group. Importantly, we note some discord in the results across the tests conducted. We ran the different tests in order to allow comparison with previous results reported by Ackermann et al. (2020) as well as to go beyond these results (with regards to the linear mixed-effects model) to get a clearer picture of the factors influencing word recognition and retention.

Furthermore, we ran and report the correlations merely to document that the results reported in the linear mixed-effects model were consistent with simple correlations and not an artefact of the effects added to the model. While the t-tests suggest that children recognize (when tested immediately after learning) and retain (when tested five minutes later) word-object mappings from only high arousal categories, i.e., objects from categories where children showed high pupillary arousal when presented with familiar members of these categories, the correlations and the linear mixed effects model point also to arousal-related retention of the novel word-object mappings (both 5 minutes later and 24 hours later). Importantly, the results of the t-tests are in keeping with the results reported by Ackermann et al. (2020) with older children, i.e., that children showed recognition of word-object mappings from high arousal categories but not low arousal categories (to the extent that we did not find evidence for recognition of word-object mappings from low-arousal categories) immediately after being exposed to these mappings. The results of the correlations and linear mixed-effects models more strongly indicate a relationship between retention of the learned word-object mappings and category arousal.

We will focus here more on the results of the linear mixed effects model because this allows us to examine the influence of category arousal on word-object learning and retention while controlling for the effects of potentially confounding factors like category size and object arousal. These results highlight an important role for category arousal and potentially also children's familiarity with the category (bearing in mind issues with the skewed nature of the parental ratings) on young children's retention of word-object mappings. These results highlight the importance of interest in a natural category in children's learning and retention of word-mappings of objects from these categories and provide a promising extension to the results of Ackermann et al. (2020), which speak to the role of interest on children's immediate recognition of learned word-object associations.

These findings are in accord with the literature on long-term word learning across two fronts. On the one hand, our finding that interest in a natural category is related to retention of word-object mappings from this category is consistent with research on children's extremely intense interests, suggesting that children learn and retain information of interest in the long-term. Furthermore, our results are also consistent with findings that two-year-olds do not retain a learned novel label-object mapping when tested with a five-minute delay unless the salience of the target object is increased during learning. In the present study, we set out to examine whether interest in the category to which the object belongs can increase salience in a similar way and thus facilitate word retention even at 24 months. Thus, for the younger children, interest in the category to which an object belongs – as indicated by the pupillary arousal measure – is related to children's retention of the label for this object even when it comes to longer time scales.

Next, we focus on the results with the older children. Here too, the results were quite mixed across the analyses reported. As with the two-year-olds, we will focus on the results of the linear mixed effects models, controlling for the influence of other predictors, i.e., object arousal, category size, while examining the influence of category arousal and parental reports on word recognition and retention. These results suggest that three-year-olds easily learn and retain the novel word-object associations presented to them. This finding is highly consistent with earlier research suggesting mixed evidence for retention early on while reporting robust evidence for retention from 30-months on (Bion et al., 2013). This is also in keeping with our knowledge of child lexical acquisition in this later stage of development. By age three, children have become sophisticated learners, whose vocabularies have typically grown so much that they can barely be captured by standardized questionnaires anymore – the MBCDI and its international adaptations go up to three years. This is thus corroborated by data from children's vocabulary acquisition "in the wild".

We found limited evidence for a role of interest in the category on learning and retention at this older age-group. This is in line with curiosity-driven approaches to learning and development that show a beneficial influence of curiosity on learning in the age group tested here (Partridge et al., 2015) as well as in adults (Kang et al., 2009). Our results suggest that category arousal influences retention of the novel word-object associations when children were tested 5 minutes after learning but we note that this effect was no longer significant when controlling for children's curiosity and familiarity in the category (as indicated by parental ratings). While we urge caution in interpreting the model including the parental ratings, our findings would suggest small effects of category interest on word learning at this older age that are potentially confounded with other factors shaping the developing lexicon. At 38 months, children recognize the novel words regardless of category size or category interest and delay in testing, suggesting that the impact of these factors level off as children learn more words. As noted in (Ackermann et al., 2020), overall learning would be limited if interest was the sole driving force of acquisition. Indeed, the successful learner must overcome their initial interests and acquire information from more varied sources about a greater breadth of objects in their environment and three-year-olds appear to be well on their way to such breadth of learning.

Next we turn to the parental reports and the influence of category knowledge and category interest (as indexed by these parental reports) on word learning in the long-term. First, we note that parental ratings of curiosity do not correlate with the pupillary arousal measure. This finding echoes Ackermann et al. (2020) who found that parental and pupillary measures modulated recognition in strikingly similar ways despite not being correlated with one another. Second, we note that in the present study, parent-rated familiarity in the category to which the object belongs, but not curiosity, modulates retention of learned word-object mappings in the younger children. One explanation for this difference may be that we changed the questionnaire sent to parents in the current study to include further questions about children's curiosity and familiarity in the categories tested. This was based on the results of Ackermann et al. (2020) suggesting that parents may be computing how curious their child is in a category based on their knowledge of how many words their child knows in that category. Indeed, the current results, including both curiosity and familiarity in the model suggest that parents' knowledge of how familiar their child is with a particular category (which may itself be driven either by the input or by how interested that child is in the category) may predict children's retention of newly learned word-object associations from those categories.

This raises the question with regards to what the measures are tapping into precisely and how this relates to theories of interest. Theories typically define interest as a predisposition to repeatedly engage with particular kinds of stimuli (e.g. Hidi & Renninger, 2006), while further breaking this concept down into *situational interest*, an externally triggered predisposition to engage with a particular content due to its novelty, relevance or personal involvement in such content, and *individual interest*, a typically self-generated predisposition to *repeatedly* engage in particular kinds of content. While situational interests may develop into well-formed individual interests, this may not always be the case.

We suggest that when asked about their child's familiarity with and curiosity towards objects and categories, caregivers might be more likely to think of their child's *individual* interests. Individual interests are characterized by repeated engagement with a category or object, such as question-asking behaviour and interaction (Hidi & Renninger, 2006). Individual interest typically operates on a longer timescale, making it more noticeable to outsiders like parents and caregivers (cf. DeLoache et al., 2007). Furthermore, Hidi and Renninger (2006) as well as Grossnickle (2016) note that increased interest leads to increased knowledge about a topic. Parental ratings of curiosity and familiarity may therefore more likely reflect children's stable, long-term interests and past behaviours. Here, we find evidence that children's familiarity with particular object categories – independent from their pupillary arousal upon being presented with these categories – may modulate children's retention of word-object mappings from these categories.

Given the lack of a significant correlation between children's category arousal and the parental reports, we then address the question of what the measure of category arousal may be tapping into. One possibility is that category arousal may map onto situational interest, a potentially fleeting predisposition to engage with a particular content due to its novelty, relevance or personal involvement in such content. Such situational interests may be externally supported as was the case here where children were exposed to familiar members of the different categories leading to an in-the-moment increased interest in particular kinds of objects. Here, we find that such in-the-moment effects – as in the case of Horst and Samuelson (2008) – may lead to children showing increased retention of labels for objects from high arousal categories.

Admittedly, however, as noted in Ackermann et al. (2020), the significant correlations between the parental ratings of children's curiosity and familiarity in the and category size may also reveal a potential shortcoming of the measures employed here. While broader semantic categories might indeed be a result of a sustained interest in the category, it is also possible that parents conflate category size, category interest and familiarity with a category. Curiosity and familiarity ratings might thus be closely related to children's vocabulary structure, equating bigger categories with increased interest and greater familiarity.

Importantly, in the model including parental ratings and category arousal as predictors, parental familiarity ratings and category arousal independently modulate retention in the younger age group, despite not being correlated with each other. On one reading of these findings discussed above, this would suggest that both situational and individual interest contribute to children's retention of novel word-object mappings. On another more conservative reading, this would suggest that some measure of category-based arousal or interest as well as a measure of children's category knowledge independent of each other are related to children's retention of novel word-object mappings.

In conclusion, the current study highlights a key role for the child – and her interest in particular object categories – as a critical source of variability in early word learning, while highlighting the need for more work to understand the extent to which parents are aware of and can report on their children's interests and its influence on word learning. Ongoing work in our lab is currently investigating this on a longitudinal scale. At the same time, this work underscores the developmental trajectory of word-object learning and retention between two and three years of age, replicating previous results of limited retention of learned mappings early in development and more robust evidence for such retention later in development.

Chapter 4

The role of interest in resolving referential ambiguity

4.1 Introduction

Young children are astonishing word learners: At the end of their first year of life, typically developing children produce only a handful of words (Frank et al., 2017). Over the second year of life, children's productive vocabularies grow to an average of 200 words, and by age 30 months, children produce more than 400 words. This rapid growth is especially remarkable as the visual scenes that children encounter in their day-to-day lives are heavily cluttered (Clerkin et al., 2017). In their everyday visual environments, children are constantly faced with referential ambiguity: word learning relies on linking words to their corresponding real-world referents, but for every word that a child hears, there are several potential referents in the visual environment. Thus, often when a child encounters a novel word for the first time, its meaning is usually underdetermined (cf. Quine, 1960), as one-to-one correspondences between the novel word and its intended referent in the visual scene are rare.

In everyday learning situations, children have to simultaneously parse cluttered visual scenes and the accompanying auditory input in order to determine correct word-referent mappings. Therefore, referential ambiguity has been identified as one of the major challenges children face in early word learning and has been an ongoing topic of investigation for more than 30 years (Clerkin et al., 2017; Samuelson & McMurray, 2017b). Over time, different solutions to the puzzle of referential ambiguity have been proposed, ranging from highly-specialized domain-specific constraints to more general attentional biases. The current study adds to the increasingly popular approach that domain-general processes underlie early word learning (Samuelson & McMurray, 2017b): Here, we explore to what extent children's interest in a novel object and its semantic category influence their word-object-mappings in the absence of other cues.

4.1.1 Navigating referential ambiguity

How might children resolve referential ambiguity? A number of cues and strategies have been proposed to underlie children's navigation of ambiguous learning situations to successfully map words onto their referents.

One of the earliest proposed constraints that guides children's word learning and helps them rule out certain referents in an ambiguous learning situation is mutual exclusivity. Markman (1990); Markman and Wachtel (1988) argues that children reject a second label for a name-known object and instead assign the label to a novel object. Since then, this mutual exclusivity bias has been examined in greater detail across different age groups and from a range of theoretical backgrounds (e.g. Diesendruck & Markson, 2001; Halberda, 2003, 2006; Mather & Plunkett, 2009, 2010, 2012). However, as mutual exclusivity is a process of elimination, it presupposes that the distractors and their labels are known and can thus be rejected as potential referents of the novel word. In real-world situations, children might be confronted with situations in which no name-known distractors are present, rendering mutual exclusivity useless to determine the correct mapping.

In situations with name-unknown distractors, other biases have been shown to guide children's referent selection: Horst et al. (2011) familiarized children with novel objects without labelling them. When children were presented with two previously seen and one completely novel object, children assigned a novel label to the previously unseen object, indicating a novelty bias. This bias towards novel stimuli is not language-exclusive and underlies much of children's curiosity-driven exploration (cf. Twomey & Westermann, 2018).

Social-pragmatic approaches (Tomasello, 2000) highlight the importance of social interaction and social information in the word learning process. In the interaction with an adult, children are sensitive to pragmatic information when confronted with referential ambiguity. Adults might provide ostensive or non-ostensive cues to the correct word-referent-mappings that children as young as 18 months can pick up on to resolve an ambiguous learning situation. Word learning - seen in the social-pragmatic tradition as a form of cultural learning (Tomasello, 2000) - relies on understanding communicative intentions: Word-object-mappings are constrained by what is relevant in a given situation, with relevance being established by pragmatic cues. An emphasis is placed on the role of joint attention (Tomasello, 1995; Tomasello & Kruger, 1992): Jointly attending to a potential referent of a novel word serves as a way to constrain possible mappings. At 19 months, children already make use of joint attention by taking the adult's gaze direction into account when determining the referent of a novel word (Baldwin, 1993). Moreover, children's understanding of adults' communicative intentions guides their referent selection: Two-year-olds map novel verbs onto intentional, but not accidental actions (Tomasello & Barton, 1994), while 18-month-olds learn a novel word after an adult announced their intention to find the referent (Tomasello, Strosberg, & Akhtar, 1996). Along the same lines, other subtle pragmatic cues such as the adult's excitement about a novel object have also been shown to influence children's referent selection (MacPherson & Moore, 2010; Tomasello, 2003): At age two, children take this social information into account when determining the referent of a novel word. In a social-pragmatic framework, children make use of sophisicated social-cognitive skills that are not unique to the language domain when navigating referentially ambiguous situations.

It should however be noted that these laboratory word learning tasks bear very little resemblance to children's everyday visual environments. Lab-based word learning studies carefully control for the number of and familiarity with distractors as well as for previous exposure to the novel objects and their labels while also limiting the sources of information (Horst et al., 2011).

In their day-to-day learning environments, these factors cannot be controlled for. Instead, children are confronted with cluttered visual scenes and auditory input that have to be parsed over longer periods of time to successfully map words to referents and eventually retain these mappings. It therefore seems plausible that children make us of cross-situational word learning, i.e. track the statistics of co-occurrence of labels and objects across different situations and then use the aggregated data over time to infer word-object-mappings. There is evidence for cross-situational word learning from laboratory studies (L. Smith & Yu, 2008), but recent insights into children's real-world visual environments have challegend the importance of cross-situational learning as a word learning mechanism in young children. Using home recordings obtained from head-mounted cameras, Clerkin et al. (2017) found that visual scenes in the everyday learning environment are indeed cluttered, but that the frequency distribution of objects across scenes is highly skewed: a small number of objects appears repeatedly across situations. These visual statistics help children determine the correct referent of a word, as they make some objects much more likely contenders than others. Clerkin et al. (2017) note that these highly frequent objects are correlated with children's first-learned words, highlighting the importance of visual familiarity for early word learning: Instead of (solely) relying on tracking co-occurrences of words and objects, as they would have to in a controlled laboratory study, children can also pick up on information available in the environment to guide their word learning.

Additionally, the process of word learning operates on different timescales that should also be taken into account when discussing how children resolve referentially ambiguous learning situations. Apfelbaum and McMurray (2017) emphasize the dynamic nature of word learning and the importance of real-time processes in word learning. Across a range of experiments with adult learners, they show that learning is not merely a product of visual and auditory processing, but that the learning process begins while perceptual processing is still ongoing. With regard to referential ambiguity, this means that mappings are formed and updated as the visual and auditory information unfold: Mappings might be revised in light of new evidence throughout the learning event.

Samuelson and McMurray (2017b) note that most traditional explanations of resolving referential ambiguity rely on the assumption of language-specific constraints. They argue for a shift towards explaining early language development via domain-general mechanisms such as statistical learning (cf. Clerkin et al., 2017), attention (cf. Kidd et al., 2012, 2014), or novelty (cf. Twomey & Westermann, 2018): While children's abilities to quickly learn new word-objects-mappings and to resolve ambiguity can make it look as if they come into the world with domain-specific constraints, recent research suggest that children's performance in these tasks can also be explained by less sophisticated mechanisms that they make use of in a number of domains. This observation is in line with Horst et al. (2011), who note that most lab-based studies investigating referential ambiguity manipulate the source of information while not taking into account domain-general cognitive biases – such as a novelty bias – the child might bring to the table. Horst et al. (2011) emphasize that these endogenous biases create an uneven playing field in traditional word learning studies: In most referent selection tasks, the cues provided by the experimenter compete with biases that cannot be controlled for, making it difficult to tease apart the contributions of external cues and internal biases. The present study aims to even the playing field by eliminating statistical, syntactic or pragmatic cues and giving center stage to one kind of bias, namely the children's interests in the novel objects and the categories they belong to.

Indeed, recent approaches to early learning capitalize on these endogenous biases by placing the child in a more active role and focusing on how children explore and shape their own learning environment. These active learning approaches to early development give special consideration to interest (e.g. Hidi & Renninger, 2006) and curiosity (e.g. Oudeyer & Smith, 2016; Twomey & Westermann, 2018) as the driving forces behind attention and learning: Research has shown that children will request information about and preferentially attend to what they are interested in, which in turn leads to better learning outcomes. In infants as young as 8 months, curiosity enhances attention and incidental learning (Chen, Westermann, & Twomey, 2021), while 10-month-olds allocate their attention to maximize learnability from the environment (Poli et al., 2020). 16-month-olds actively use pointing gestures to specifically elicit information about objects in the environment (Begus & Southgate, 2012) and retain information best that was provided at their request (Begus et al., 2014). Older children also benefit from an active choice of learning materials in a word learning task (Partridge et al., 2015).

The beneficial influence of curiosity and interest has also been attested in the domain of early word learning. In a word learning study with 30-month-olds, Ackermann et al. (2020) add to this interest-driven approach in two ways. While other studies use explicit measures of interest and curiosity such as pointing (Begus & Southgate, 2012) or tapping on a touchscreen (Partridge et al., 2015), Ackermann et al. (2020) measure changes in pupil dilation reflective of children's arousal. Additionally, Ackermann et al. (2020) show that the beneficial influence of interest extends to the category level as well: Children recognized novel word-object-associations more robustly if the target came from a category they were more interested in, as suggested by their pupillary arousal to familiar category members.

This line of research opens up a new and promising look at referential ambiguity. Most studies to date have focused on children's usage of different pragmatic, social or syntactic cues by examining whether a certain experimental manipulation biases the child towards a potential referent. As argued by Horst et al. (2011), these studies aim to reduce the influence of children's endogenous biases and instead highlight the role of outside information. However, recent research has shown that children's interests and preferences guide their learning and attention. If children structure their own learning environment by preferentially attending to and learning from stimuli that are interesting to them, interest might also help them navigate an ambiguous word learning situation in the absence of all other cues and sources of information. On the other hand, it should be noted that a purely interest-based word-referent-mapping could also lead children the wrong way. Therefore, it is important to explore whether and to what extent interest actually plays a role in guiding referent selection in ambiguous situations.

4.1.2 The current study

The current study explores to what extent interest guides children's referent selection in referentially ambiguous situations in which they are unsure of the one-to-one correspondences between two novel objects and a novel label. Here, children are presented with two novel objects from different categories while hearing only one novel label. Importantly, we eliminate statistical and pragmatic cues that have been shown to help children resolve ambiguity – in the word learning situation, both novel objects are equally likely to be the referent of the novel word: Children see both potential referents simultaneously and for the same amount of time while hearing the novel label, eliminating the possibility to track co-occurrences across situations or use novelty and/or familiarity as a clue. Children are furthermore not provided with ostensive or subtle pragmatic cues that could bias them towards one referent.

This particular learning situation has several conceivable outcomes: The first possibility is that children do not distinctly assign the novel label to either of the two objects, as they do not have sufficient information to determine the "correct" referent. This is in line with multiple mapping approaches (e.g. McMurray et al., 2012): Initially, one word will be mapped onto more than one referent, but incorrect associations will be pruned as evidence accumulates over time. The other possible outcome is that children form a stronger association between the label and one of the two objects. We are particularly interested here in the extent to which this association could be based on their interest in the object itself or in the category to which the object belongs. It could also be the case that they assign the label to an object, but that there is no evidence for this assignment being guided by their object interest or category interest. In that case, further research is needed to determine what influences word-referent mapping.

To test the different possibilities, we present 30 to 36 months old children with ambiguous word learning situations in an eyetracking experiment. The present study examines different measures of children's interest: First, we measure children's pupillary arousal in response to pictures from different natural categories. As changes in pupil dilation have been shown to correlate with self-reported curiosity in adults (Kang et al., 2009) and have successfully been used as a measure of interest in children (Ackermann et al., 2020), heightened pupillary arousal to pictures of familiar category members is interpreted as increased interest in this category (henceforth, category arousal). Similarly, we measure children's pupil dilation in response to pictures of the novel category members and interpret heightened pupillary arousal as interest in the novel object itself (henceforth, object arousal). Our third measure of interest is relative looking time: When children are shown pictures of the two novel objects side-by-side, longer looks to one picture relative to the other are interpreted as greater interest in this picture (see Lang, Greenwald, Bradley, & Hamm, 1993; Russell, 1975, , for correlations between looking time and self-reported interest in adults). The fourth measure is based on parental ratings of their child's interest in the semantic categories used in the study.

The eyetracking part of the study builds on the design of Ackermann et al. (2020) and consisted of three phases. In the arousal phase, children saw pictures of 16 familiar and four novel objects from four different early-acquired semantic categories. We measured changes in pupil dilation following presentation of the pictures as an index of their arousal. In the word learning phase, children were exposed to a referentially ambiguous situation: They saw two novel objects from two different categories side-by-side but were exposed to only one novel label across 10 naming events. In this phase, we measured children's looking time to both objects to determine relative interest in one object over the other. In the subsequent word recognition phase, we used the intermodal preferential looking paradigm (Golinkoff et al., 1987) to test whether children had assigned the label to one of the two objects and whether to what extent interest guided their assignment of the label. Children were tested in two conditions, learnt label trials and supernovel label trials. In both conditions, children saw the two novel objects side-by-side. In the learnt label trials, children heard the just-learnt label, while they heard a completely novel label in the supernovel label trials (see Fig. X). We then analyze to what extent referent assignment in the learnt label trial was driven by category arousal or object arousal. Supernovel trials allow us to test that performance in the learnt label trials does not merely mirror children's visual preference from the learning phase. If children's looking behaviour at test was driven by their preference for one object over the other, they would also look more at the preferred object in the supernovel label trial. Increased distractor looking in the supernovel label trials serves as evidence that looking behaviour is an index of an association being learnt: If one of the object has become a name-known object, we expect the previously unheard label to be assigned to the name-unknown object.

4.2 Methods

4.2.1 Participants

49 children aged 29 to 36 months (M = 33 months, 4 days, range 29 m 8 d to 36 m 4 d, 25 female, 24 male) were recruited from the institute's database. Two children were excluded prior to data analysis for not completing the experiment (n = 1) and

Table 4.1: Familiar objects used in this study, percentage of 30-months-old children who are reported to know this word (according to FRAKIS data, Szagun et al. (2009)), and percentage of participants (N = 39, as not all children provided FRAKIS data) reported to know this word.

Category	Object	Known % (FRAKIS)	Known % (participants)
Food	Apple	97.85	100
	Yoghurt	93.55	97.44
	Potato	93.55	100
	Bread	94.62	100
Furniture	Bench	69.89	89.74
	Armchair	68.82	92.31
	Bed	97.85	100
	Table	96.77	100
Vehicles	Motorcycle	83.87	100
	Tractor	86.02	100
	Digger	95.70	100
	Airplane	92.47	100
Animals	Cat	96.77	100
	Duck	96.77	100
	Hedgehog	84.95	100
	Fox	63.44	94.87

technical difficulties (n = 1). Two additional children were excluded for not providing at least two test trials per condition. All 45 remaining children were born full-term, had normal hearing and vision and were reported to be monolingual learners of German. In return for their participation in the study, children received a book. The study was reviewed and approved by the institute's ethics committee.

4.2.2 Stimuli

From each of the four early-acquired semantic categories FOOD, FURNITURE, ANIMALS and VEHICLES, we chose four objects to serve as familiar objects during the category arousal and word recognition phases. All familiar objects are reported to be known to more than 50 % of German-learning children at 30 months according to the FRAKIS (German adaptation of the MBCDI, Frank et al., 2017; Szagun et al., 2009). An overview of the percentage of children in this study reported to know each word can be found in Table 4.1. Additionally, we chose one rare member from each category to serve as a novel object in the word learning phase of the experiment (see Table 4.2 for an overview of all novel objects).

Table 4.2: Novel items from the four categories.

Animals	Food	Vehicles	Furniture
Slow loris	Mochi	Segway	Easel
			

For each familiar and novel object, a photorealistic image measuring 400 x 400 px was created and pictured against a light grey background. In the category arousal phase, we used a diffeomorphed, i.e. warped, version of each image to serve as the baseline for the pupillary measure (Stojanoski & Cusack, 2014, see Figure 4.1). Changes in pupil dilation from the unidentifiable warped baseline picture to the clear picture were interpreted as reflecting the child's interest in the content of the picture: Importantly, the diffeomorphic transformation preserves the approximate colour distribution and overall luminosity of the original image, controlling for possible influence of the physical properties of the picture on the pupillary response (cf. Ackermann et al., 2020; Hepach & Westermann, 2016). The diffeomorphic transformation was carried out in MATLAB, using the script provided by Stojanoski and Cusack (2014).

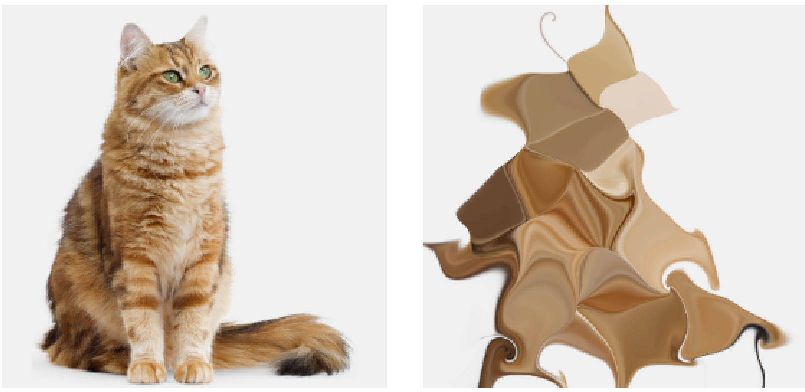


Figure 4.1: Example of an image before and after diffeomorphic transformation. The degree of warping was set to 30 %. This follows Stojanoski and Cusack (2014) who found that adult participants were unable to identify the objects at this degree of warping.

Auditory stimuli were recorded by a female native speaker of German in an enthusiastic, child-directed voice at a sampling rate of 44,100 Hz and filtered for environmental noise using Goldwave. In the category arousal phase, speech stimuli consisted of the definite article (der, die or das) followed by the object label for familiar objects, and “Schau mal!” (“Look!”) for the novel objects. In the word learning phase, the novel label was embedded into five different carrier sentences with a total length of 15 s: Schau mal, eine [target]! Das ist eine [target]! Siehst du die [target]? Da ist eine [target]! Wow, eine [target]! (”Look, a [target]! This is a [target]! Do you see the [target]? There is a [target]! Wow, this is a [target]!”). All labels used to refer to the novel objects (DOFFI, KOLAT, WIDEX, BATSCHA) were bisyllabic and conformed to the phonotactic rules of German. In the word recognition phase, children were prompted to look at an object with one of two auditory prompts: “Siehst du das [target]?” (“Do you see the [target]”) or “Wo ist das [target]?” (“Where is the [target]?”).

Parents were asked to fill out a shortened version of the FRAKIS (Szagun et al., 2009) containing only words from the four categories used in the study. Additionally, parents were asked whether their child knew any of the novel objects used in the study. For each of the four categories, we asked parents to choose two out of the four familiar category members that they consider typical exemplars of this category for their child. Based on this selection, we then asked parents to rate (a) how familiar their child is with this category, (b) how curious their child is about this category, (c) how often their child asks questions about this category, and (d) how much joy interaction with this category brings their child, on 7-point Likert scales.

4.2.3 Procedure

Eye movements were recorded using a Tobii X 120 eye tracker with a gaze sampling rate of 120 Hz and a pupil diameter sampling rate of 40 Hz. During the experiment, children were seated either in a car seat or on their parents’ lap approx. 65 cm away from a 40 inch screen. Stimuli were displayed using Tobii Pro Studio (version 3.4). The eyetracking experiment lasted approx. 7 minutes.

The experiment was divided into three phases. In the category arousal phase, children saw all 16 familiar and 4 novel objects across five blocks. Each block contained one object from each category. The order of blocks and the order of objects within blocks was counterbalanced across children, with the exception of the second block, which always contained all four novel objects (see Appendix/Suppl. Material for counterbalancing). After each block, a 10 s video of bubbles was played as an attention getter. In each familiar trial, children first saw a warped version of the image for 3000 ms which served as the baseline for the pupillary measure (see Fig. 1 for an example) before the unwarped image appeared for another 1000 ms. The label was presented 1000 ms into the unwarped phase. Timings were identical for novel trials, but instead of the label, the prompt "Schau mal!" ("Look!") was played.

The word learning and word recognition phases were split into two blocks, with the first word recognition block immediately following the first word learning block. In each word learning block, children were presented with two of the four novel objects and one novel label. Children were presented with two learning trials per block. In each learning trial, the two novel objects were shown side-by-side for 15s while the label was played five times, embedded in five different carrier sentences. In the second learning trial, the objects switched sides, but the label remained the same, resulting in a total of 10 naming events.

In the word recognition phase, we tested whether children had assigned the label to one of the two objects and to what extent this assignment was modulated by the different interest measures we collected. The word recognition phase consisted of eight test trials: four familiar trials, two learnt label trials and two supernovel label trials. In each test trial, children saw two objects side-by-side in silence for 3000 ms before a colourful center stimulus appeared. Once children fixated the center stimulus, the images reappeared together with an auditory prompt containing either the just-learnt label (learnt label trials) or a previously unheard label, with the onset of the label starting 1,200 ms after the reappearance of the images. From the onset of the label, the images remained on screen for 2,500 ms, resulting in a total length of 3,700 ms for the critical period of the test phase.

In the familiar trials, two of the 16 familiar objects from the category arousal phase were paired with each other. In the learnt label trials, the two previously seen novel objects were shown side-by-side and the auditory prompt used the just-learnt label, embedded in one of two carrier sentences. In the supernovel label trials, the two previously seen novel objects appeared on screen, but the label was one the child had not previously heard (see Figure 4.2 for an example). If a child has indeed assigned a label to one of the two objects, this object becomes a name-known object. Following the principle of mutual exclusivity, the child should now assign the supernovel label to the name-unknown object.

After the first word recognition block, the child saw the second learning block in which the two other novel objects and one other novel label were introduced. Again, the word learning block was followed by a word recognition block consisting of the eight test trials outlined above. The novel animal and the novel vehicle always appeared together, as did the novel food item and the novel piece of furniture. This pairing follows the assumption that overall, children might prefer animate/moving stimuli over inanimate stimuli (cf. DeLoache, Pickard, & LoBue, 2011). Grouping animals and vehicles together therefore controls for a possible bias towards moving objects. The order of learning blocks, the sides on which the novel object appeared, and the novel label used in each learning block were counterbalanced across children.

After the eyetracking experiment, children were brought out of the booth for an offline naming task. The experimenter showed the child a printout of each novel object and asked them to name it: “Wie heißt das Ding?” (‘What do you call that?’). If the child didn’t respond, the experimenter asked them if they remembered the name (“Erinnerst du dich?”, ‘Do you remember?’). Responses were written down. The order of novel objects was counterbalanced across children.

4.2.4 Preprocessing

Across three separate analyses, we calculated for each pair of objects which object each child was more likely to be interested in, based on our measures of category arousal, object arousal and relative looking time. This results in three individual assignments of the likely target for each child: Each measure yields one object that the child shows higher interest in. If interest indeed influences children’s assignment, the higher-interest object should be the one to which the child assigns the label. Although our test trials do not have a predetermined target in the sense of other lab-based word learning studies (e.g. Ackermann et al., 2020), we will henceforth refer to these higher-interest objects as targets.

Children were presented with pictures of four familiar objects from each category, while we measured changes in pupil dilation from a warped baseline image to a

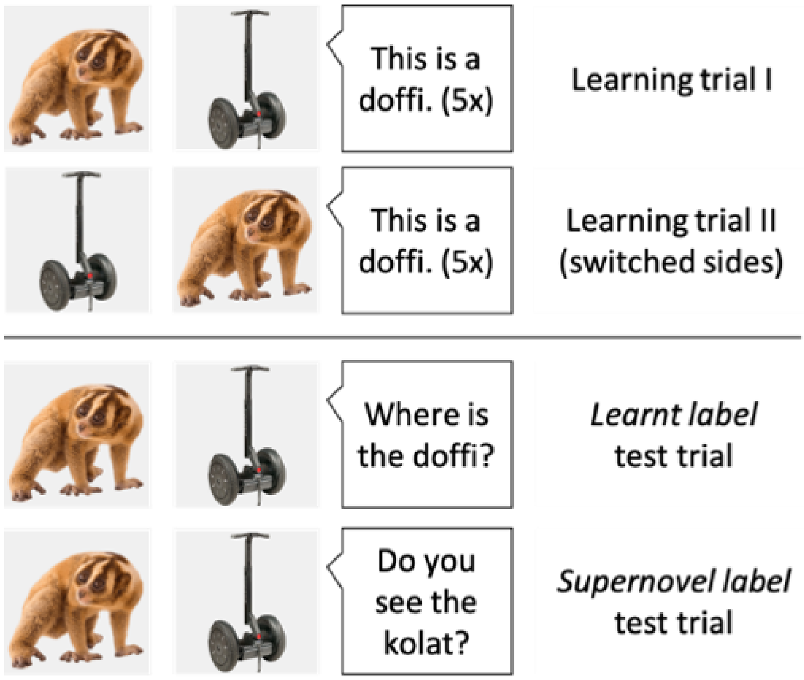


Figure 4.2: Example pairing of novel objects and labels. The child is introduced to the label *doffi*. *Doffi* is then used as the target word in the learnt label trials. In the supernovel label trials, the target word is the previously unheard *kolat*.

clear version of the image. These changes in pupil dilation across all members of one category served as our measure of category arousal. Similarly, our measure of children's object arousal is based on changes in pupil dilation in response to an image of the respective novel object. The looking time measure was based on children's proportion of looks to the two objects presented side-by-side in the learning phase, with longer relative looking to one image interpreted as higher interest.

To obtain the pupillary measure, pupil diameter was sampled at a rate of 40 Hz and aggregated into 25 ms bins offline. For each bin that was part of a fixation and where validity was good, we then calculated pupil dilation separately for each eye. In a next step, we calculated the difference in pupil dilation between adjacent samples and used a threshold filter that excludes all data points in the top ten percent of differences, as these deviations are likely to be artefacts. Following Hepach, Vaish, and Tomasello (2012), we interpolated missing data points with a sample size of four. Pupil size was then averaged for both eyes and baseline corrected, with the 500 ms immediately preceding the onset of the label serving as the baseline. This baseline-corrected measure of pupil dilation was then averaged across all four familiar members of a category to obtain the category arousal measure for each child.

The baseline-corrected pupillary measure on each novel object served as the object arousal measure. For each child and each object pair (lori/Segway and mochi/easel), the category arousal measure yielded one higher-interest category, i.e. the category to which the child showed relatively higher changes in pupil dilation. The novel object from this higher-interest category was then identified as the target, i.e. the object the child would be more likely to assign the label to based on category arousal. Similarly, we assigned a target individually for each child based on the object arousal measure. Again, we compared changes in pupil dilation for both novel objects in an object pair and identified a higher-interest object, namely the novel object from each pair to which the child showed higher pupil dilation.

In a next step, we determined which object in each pair the child was more interested in based on the amount of time they spent looking at one object relative to the other. For this target assignment, we calculated the proportion of looks to each object in the learning phase, where both objects of each pair were presented to the child simultaneously. Gaze position was sampled at 120 Hz and aggregated into 40 ms bins offline. For analysis, we only retained bins that contained fixations (as identified by the eyetracker's automatic classification) and where validity was good. We then calculated the proportion of object looking for each object as the total amount of time children spent looking at this object divided by the total amount of time spent looking at both objects. The object that children spent relatively more time looking at was identified as the higher-interest object, i.e. the more likely target. The three separate analyses thus resulted in three target assignments per child per object pair: Each measure yielded one higher-interest object that was treated as the target in our subsequent analysis of proportion of target looking. Note that the target assignments were not necessarily consistent across the different measures.

In a next step, children's proportion of target looking (PTL) was calculated to assess children's looking behavior in the word recognition phase. For each test trial, we calculated PTL by dividing the amount of time children looked at the assigned target by the overall looking time to target and distractor. Importantly, this was done across three separate analyses for each target assignment (looking time, category arousal and object arousal): Individually for each child, we first treated the higher-interest object as indicated by relative looking time as the target, while the other

Object pair: mochi / easel

Object arousal measure (determines higher-interest object)	Change in pupil dilation in response to picture of novel object **mochi** > easel
Object arousal target	mochi 
PTL based on object arousal target	$\frac{Looking\ time\ at\ mochi}{Looking\ time\ at\ mochi + Looking\ time\ at\ easel}$
Category arousal measure (determines higher-interest category)	Average change in pupil dilation in response to pictures of familiar objects **furniture** > food
Category arousal target	easel 
PTL based on category arousal target	$\frac{Looking\ time\ at\ easel}{Looking\ time\ at\ easel + Looking\ time\ at\ mochi}$
Looking time measure (determines higher-interest object)	Relative looking time while pictures are presented side-by-side **easel** > mochi
Looking time target	easel 
PTL based on target	$\frac{Looking\ time\ at\ easel}{Looking\ time\ at\ easel + Looking\ time\ at\ mochi}$

Figure 4.3: Schematic overview of the process of target assignment for one individual child and one object pair.

object was treated as the distractor. Similarly, we calculated PTL following the target assignments based on the two pupillary measures, treating the higher-interest object as the target to calculate PTL based on object arousal, and treating the object from the higher-interest category as the target to calculate PTL based on category arousal. The process of assigning targets and calculating PTL is summarized in Figure 4.3 schematically for one individual child and one object pair.

On a trial-by-trial basis, PTL in the postnaming window (1200 to 3700 ms into the trial) was corrected for PTL in the prenaming window (0 to 1200 ms into the trial). As common in the literature (Swingley et al., 1998), the critical time window for analysis was identified as starting 240 ms after the onset of the target word.

Table 4.3: Overview of the assigned targets across object pairs and the three interest measures.

	Object pair mochi / easel		Object pair slow loris / Segway	
	Mochi (food)	Easel (furniture)	Slow loris (animal)	Segway (vehicle)
Looking time (n = 45)	39	6	33	12
Category arousal (n = 44)	18	26	13	31
Object arousal (n = 38)	7	23	13	21

4.3 Results

For each interest measure and resulting target assignment, we examined the influence of this measure on children's target looking behavior in learnt label and supernovel label trials using t-tests and linear mixed-effect models (LMMs). The distribution of target assignments for each measure and each target pair is detailed in Table X. Note that not all children provided data for all comparisons for the object arousal measure. As Table 4.3 suggests, target assignments were not necessarily consistent for individual children across the three different interest measures. The looking time measure suggests that most children are more interested in (i.e. spent more time looking at) the mochi than the easel, while the object arousal measure reveals that most children showed a greater change in pupil dilation in response to the easel. The category arousal measure shows that the majority of children is more interested, based on the averaged pupillary measure in response to familiar items, in furniture than in food. For the second pair of objects, a similar picture emerges: Most children look longer to the slow loris than to the segway, but show a stronger pupillary response to the segway. On the category level, most children are more interested in vehicles than animals, based on the pupillary measure. This is also visualized in Figure 4.4.

4.3.1 Looking time

As outlined above, the object to which a child showed longer relative looking in the learning phase was treated as the target in this analysis, as longer looking was interpreted as higher interest. Based on this target assignment, we calculated children's

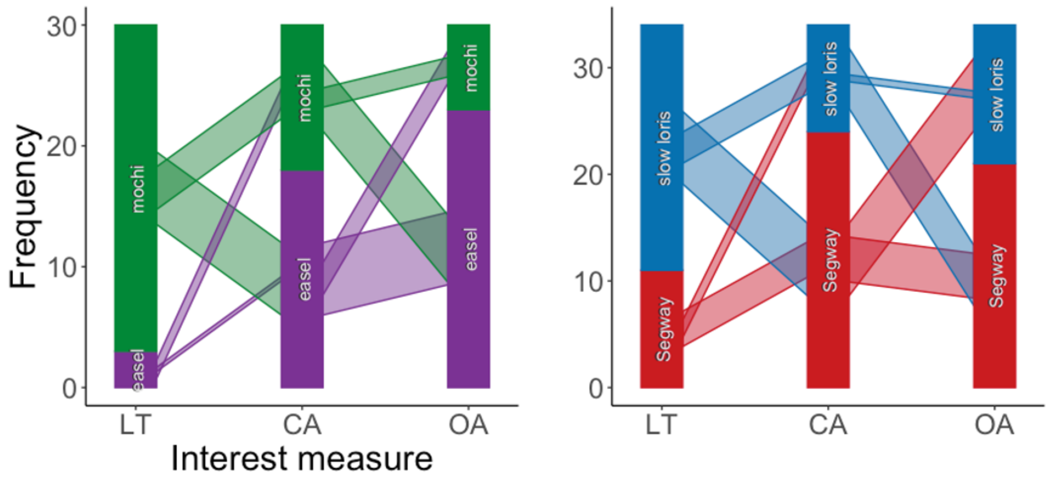


Figure 4.4: Consistency of assigned targets across children and measures (LT = looking time, CA = category arousal, OA = object arousal). This overview only includes complete cases, i.e. children that provided data for all three measures.

PTL in learnt label and supernovel label trials. If increased looking to one object over the other during the learning phase modulates target assignment, we expect that children will also show an increased PTL to this object (i.e. the assigned target) at test. Importantly, PTL is baseline-corrected, i.e. reflects the influence of the auditory label on object processing and controls for potential visual preference for one object over the other. The learnt label trials therefore allow us to test the extent to which children mapped the label to their preferred object. At the same time, we expect increased distractor looking in the supernovel label trials, indicating that children associate the previously unheard label with the name-unknown object (while the target object has become a name-known object).

The time course of target looking is plotted in Figure 4.5. Visual inspection of the time course suggests that children's target looking in learnt label trials is slightly above chance across the entire postnaming window. In supernovel label trials, children briefly look to the target before orienting their gaze to the distractor for the rest of the trial. A paired t-test compared PTL in learnt label and supernovel label trials and showed that PTL was significantly different across the two trial types, t(44)=3.012, 95 % CI: 0.036, 0.179, p=0.004, d=0.449. One-sample t-tests then examined the effect of recognition separately for each type and found a significant increase of target fixations for learnt label trials, t(44)=2.103, 95 % CI: 0.002, 0.112, p=0.041, d=0.313, but not for supernovel label trials, t(44)=-1.717, 95 % CI: -0.110,

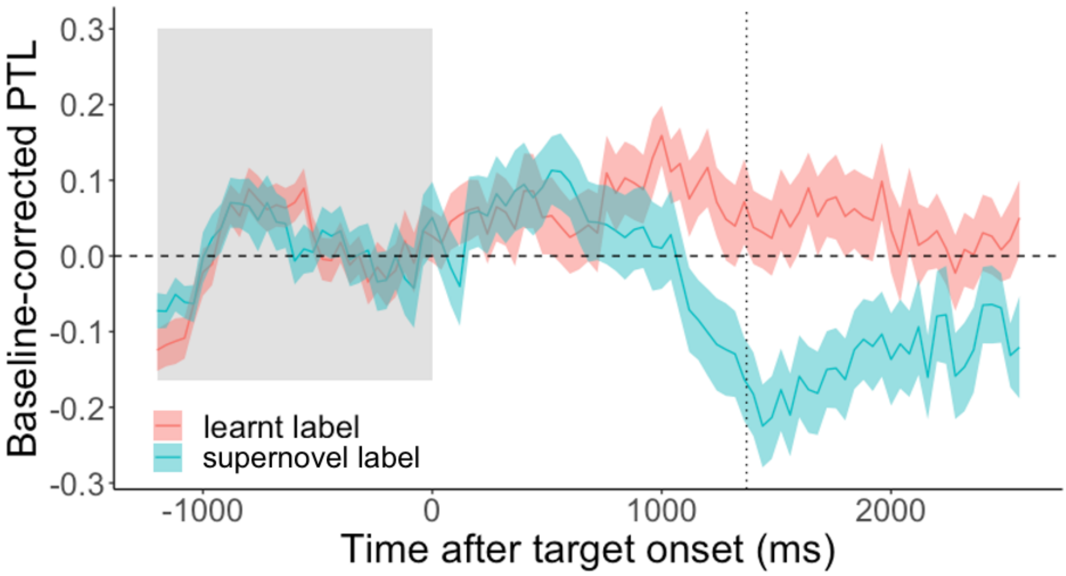


Figure 4.5: Timecourse of proportion of target looking for learnt label and supernovel label trials, with target assignments based on relative looking time in the learning phase. The shaded area indicates the pre-naming window, the dashed line indicates chance level, and the dotted line marks the beginning of the second half of the analysis window.

0.009, p=0.093, d=0.256. As the t-tests aggregates PTL over the entire time course and children start out looking to the target even in supernovel label trials, we also ran a one-sided t-test only for the second half of the analysis window (marked with a dotted vertical line in Figure 4.5). This additional t-test showed significant distractor looking in supernovel label trials, t(44)=-3.2905, 95 % CI = -0.215, -0.052, p =0.002, d=0.491, suggesting that children show a distractor preference in supernovel label trials after initially looking to the target image.

Additionally, we fitted a linear mixed-effect model to further examine the influence of looking time on PTL. We included proportion of target looking in the learning phase (PTL_learn) and trial type (learnt label vs supernovel label, sum coded) as fixed effects, and participant, target category and target item as random effects, resulting in the following model structure:

PTL PTL_learn + type + (1 | id) + (1 | category) + (1 | item)

Model results are detailed in Table 4.4. The model confirmed a significant difference in PTL across trial types ($\beta = 0.052$, t = 2.387, p = 0.017).

As trial type significantly predicted PTL and the paired t-test revealed a significant difference in PTL, we fitted separate models for both trial types. The models followed the formula outlined above. Results of these additional models are detailed in

Table 4.4: Model parameter estimates for the model including proportion of looking in the learning phase and trial type as fixed effects.

	Estimate	SE	t	p
Intercept	0.008	0.022	0.363	0.717
PTL_learn	0.202	0.184	1.101	0.271
Trial type	0.052	0.022	2.387	**0.017** *

Table 4.5: Model parameter estimates for the additional model (split by trial type) including proportion of looking in the learning phase as a fixed effect.

	Learnt label trials				Supernovel label trials			
	Estimate	SE	t	p	Estimate	SE	t	p
Intercept	0.064	0.034	1.830	0.067	-0.045	0.032	-1.402	0.161
PTL_learn	0.087	0.254	0.342	0.733	0.338	0.266	1.273	0.203

Table 4.5.

4.3.2 Category arousal

Next, we examined children's target looking using the category arousal target assignments. In this analysis, the target is the object that belongs to the category to which the child showed relatively higher pupillary arousal when presented with pictures of familiar category members. Increased target looking in learnt label trials and increased distractor looking in supernovel label trials would indicate that category arousal modulates target assignment. However, the time course of PTL (plotted in Figure 4.6) suggests that target looking remains around chance for the entire analysis window in both trial types, indicating no preference for either assigned target or distractor.

A paired t-test showed no difference between learnt label and supernovel label trials, t(43)=-0.453, 95 % CI = -0.108, 0.068, p=0.653, d=0.068. One-sided t-tests confirm that children's target looking does not deviate from chance in either trial type, t(43)=-0.031, 95 % CI = -0.061,0.059, p=0.975, d=0.005 for learnt label trials and t(43)=0.535, 95 % CI = -0.052, 0.090, p=0.595, d=0.081 for supernovel label trials, see also Figure 4.6. We find no evidence for children preferentially assigning a label to the object that belongs to the higher-interest category in a referentially ambiguous word learning situation.

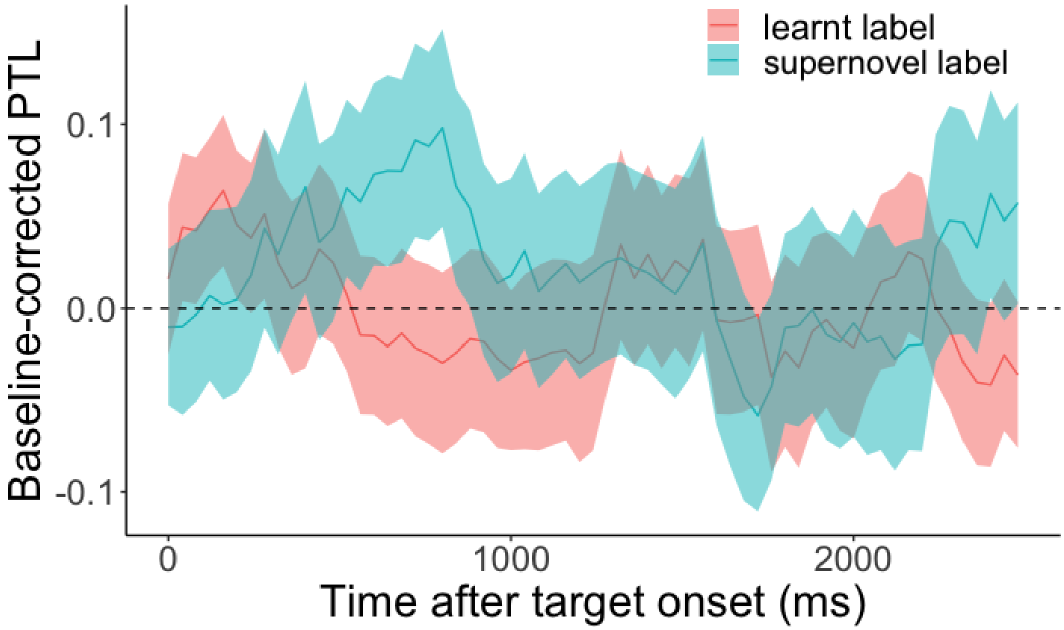


Figure 4.6: Timecourse of proportion of target looking for learnt label and supernovel label trials, with target assignments based on category arousal. The dashed line indicates chance level.

Table 4.6: Model parameter estimates for the model including category arousal and trial type as fixed effects.

	Estimate	SE	t	p
Intercept	0.004	0.024	0.157	0.875
Pupil_category	-0.095	0.230	-0.412	0.681
Trial type	-0.007	0.022	-0.341	0.733

Again, we fitted an LMM to further examine the influence of category arousal on PTL. The model followed the structure outlined above, with pupil dilation in the arousal phase and trial type as fixed effects:

PTL Pupil_category + type + (1 | id) + (1 | category) + (1 | item)

Model results are detailed in Table 4.6. In line with the results of the t-tests, the model revealed no significant difference between trial types. Additionally, the magnitude of pupil dilation in the arousal phase did not significantly predict target looking in the test phase. Again, these results show that there is no evidence for a modulating effect of category arousal on referent assignment in a referentially ambiguous situation.

Again, separate models were fitted for each trial type to further examine a potential contribution of category arousal on target looking. The details of the additional

Table 4.7: Model parameter estimates for the additional model (split by trial type) including category arousal as a fixed effect.

	Learnt label trials				Supernovel label trials			
	Estimate	SE	t	p	Estimate	SE	t	p
Intercept	-0.004	0.030	-0.124	0.901	0.011	0.034	0.331	0.741
Pupil_category	-0.158	0.305	-0.518	0.605	-0.037	0.330	-0.113	0.910

models are detailed in Table 4.7 and, consistent with the t-tests, reveal no preference for either target or distractor in either trial type and no significant effect of category arousal on subsequent PTL.

4.3.3 Object arousal

In a last step, we examined children's target looking using the object arousal target assignments. In this analysis, the object to which a child showed higher pupillary arousal was defined as the target. Note that not all children provided sufficient pupil data in the arousal phase so that OA analyses are based on n = 38.

Increased target looking in learnt label trials and increased distractor looking in supernovel label trials would indicate that object arousal modulates target assignment. Interestingly, visual inspection of the time course (plotted in Figure 4.7) reveals the opposite pattern: When targets are assigned based on object arousal, children seem to show a slight target preference in supernovel label trials and a distractor preference in learnt label trials. A paired t-test showed no significant difference between learnt label and supernovel label trials across the entire time course, $t(37) = -1.174$, 95 % CI = -0.153, 0.041, $p = 0.248$, $d = 0.190$. One-sample t-tests revealed that children's target looking did not differ from chance in either trial type, $t(37) = -0.423$, 95 % CI = -0.090, 0.059, $p = 0.675$, $d = 0.069$ for learnt label trials, and $t(37) = 1.141$, 95 % CI = -0.032, 0.113, $p = 0.261$, $d = 0.186$.

As we did for the looking time measure, we separately analyzed the second half of the time course (indicated by a dotted line in Figure 4.7) where visual inspection revealed an unexpected target preference in supernovel label trials. One-sample t-tests revealed that children's target looking did not differ from chance in learnt label trials, $t(36) = -0.800$, 95 % CI = -0.132, 0.057, $p = 0.429$, $d = 0.132$. In supernovel label

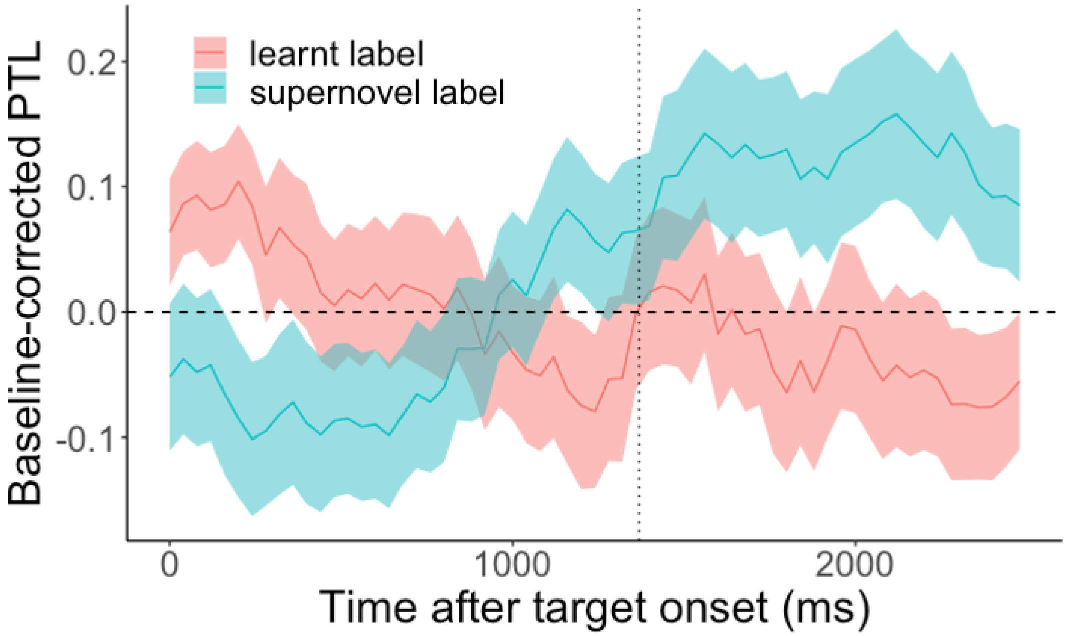


Figure 4.7: Timecourse of proportion of target looking for learnt label and supernovel label trials, with target assignments based on object arousal. The dashed line indicates chance level, the dotted line marks the beginning of the second half of the analysis window.

Table 4.8: Model parameter estimates for the model including object arousal and trial type as fixed effects.

	Estimate	SE	t	p
Intercept	0.011	0.028	0.382	0.703
Pupil_object	0.021	0.185	0.114	0.909
Trial type	-0.017	0.023	-0.724	0.469

trials, however, children show above-chance target looking in the second half of the analysis window, t(37)=2.361, 95 % CI = 0.018, 0.237, p = 0.024, d = 0.383.

Again, we fitted an LMM with pupillary arousal to the novel object and trial type as fixed effects, resulting in the following model:

PTL   Pupil_object + type + (1 | id) + (1 | category) + (1 | item)

Model results are detailed in Table 4.8. In line with the t-tests, the model reveals no significant difference between trial types and no influence of object arousal on PTL. Models separated by trial type (detailed in Table 4.9) also revealed no preference for either target or distractor and no significant influence of object arousal on target looking.

Table 4.9: Model parameter estimates for the additional model (split by trial type) including object arousal as a fixed effect.

	Learnt label trials				Supernovel label trials			
	Estimate	SE	t	p	Estimate	SE	t	p
Intercept	-0.010	0.040	-0.239	0.811	0.026	0.036	0.722	0.470
Pupilobject	-0.045	0.240	-0.188	0.851	0.018	0.256	0.072	0.943

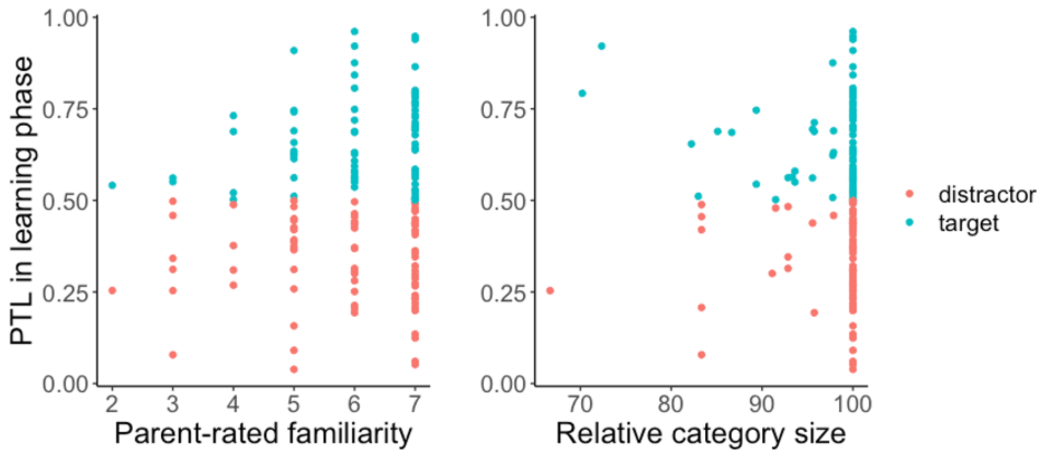


Figure 4.8: Children's object looking in the learning phase as a function of (a) parent-rated familiarity with the category to which the object belongs, and (b) children's relative category size, i.e. proportion of known FRAKIS items. Note the skewed distribution.

4.3.4 Exploratory analyses: Correlations of looking time measure with category size and parental ratings

To further examine the relation between the looking time measure and parental reports of category size and familiarity, we calculated correlations between the measures. Parents were asked to rate their child's familiarity with the categories used in the study on a 7-point Likert scale. Parental ratings of category familiarity did not significantly correlate with children's PTL to objects from this category in the learning phase, Kendall's $\tau = 0.077$, $p = 0.213$. Note however the reduced variability in parents' ratings which tend to cluster at the upper end of the Likert scale (Figure 4.8, left). Additionally, we found no significant correlation between children's relative category sizes (number of category members reported as known divided by total number of category members in the FRAKIS), Pearson's $r = 0.052$, $p = 0.521$. Again, it should be noted that most were reported to know most or all words in the respective categories, resulting in reduced variability (Figure 4.8, right).

4.4 Discussion

In an eyetracking study, we exposed 2.5 to 3-year-old children to a referentially ambiguous word learning situation in which one novel label was presented together with two possible referents. In contrast to previous studies on referential ambiguity (e.g. Baldwin, 1993; MacPherson & Moore, 2010; Markman & Wachtel, 1988; Tomasello, 2003), we did not provide any external cues to the correct word-referent-mapping. Instead, we examined if children take into account their interest in objects and natural categories to resolve ambiguous learning situations in the absence of pragmatic or social cues. We examined three measures of interest, namely looking time, pupillary arousal to the novel object itself and pupillary arousal to the category to which the object belongs. For each child and each object pair, these measures revealed which object (or category) the child is more likely to be interested in: For the looking time measure, we compared relative looking times to both objects while they were presented side-by-side. Object arousal was determined by the change in children's pupil dilation in response to a picture of the novel object. Similarly, category arousal was based on the averaged change in pupil dilation in response to pictures of four familiar members of each category. These measures allowed us to determine a higher-interest object which we then regarded as the target in subsequent analyses. For each interest measure, we analyzed to what extent it modulated children's referent assignment: If an interest measure indeed influenced how children assign a referent in this ambiguous situation, we would expect them to show a preference – as indicated by increased baseline-corrected PTL – for the assigned target during the test phase.

We found that the looking time measure modulated referent assignment: Children showed increased PTL to the higher-interest object in learnt label trials, suggesting that they indeed assigned the label to the object they spent more time looking at during the learning phase. This is corroborated by children's performance in the supernovel label trials: Here, children show a distractor preference, suggesting that they assign the previously unheard label to the name-unknown object, while the other object has become a name-known object. On the other hand, we found no evidence for category arousal or object arousal modulating referent assignment: At test, children showed no preference for either target or distractor when the target was determined based on category arousal, and even a slight distractor preference when the target was assigned based on object arousal.

Young children are constantly faced with referentially ambiguous word learning situations in which they have to map a word to one of many possible referents. Referential ambiguity has been identified as one of the major challenges of early word learning. Over the years, different explanations have been proposed for how children resolve ambiguous word learning situations, ranging from domain-specific biases and constraints to more general learning mechanisms such as statistical learning abilities and attention. Traditionally, studies examining referential ambiguity have examined children's use of language-specific constraints – such as mutual exclusivity – or their ability to make use of external cues in referent selection task. More recent approaches highlight the importance of attentional mechanisms that operate on longer time scales and emphasize the importance of repeated exposure for successfully mapping words to objects.

The current study examines how children resolve an ambiguous word learning situation with limited exposure in the absence of external clues: Children were not provided with pragmatic, statistical or syntactic clues that bias their referent assignment towards one of the two objects. Instead, both objects within a pair were equally likely to be the referent of the novel label. Here, we aim to combine recent approaches to curiosity-driven learning with the puzzle of referential ambiguity by testing whether children's interest in an object or the category to which this object belongs modulates their referent assignment, using three different measures of children's interest. In a curiosity-driven framework, special attention is given to the role of the child and their tendency to impose structure on the learning environment. In an ambiguous learning situation where no external cues to the correct word-object-mapping are provided, children's interest in the object or its category could therefore lead them to assigning a label to the higher-interest object or the object from the higher-interest category. In that case, interest would guide the child towards a particular word-referent-mapping, resolving the ambiguity and imposing structure on a learning situation. This study builds on the findings that children's interest in an object as well as in the category to which the object belongs impacts their learning and retention of word-object-associations in unambiguous word learning situations (chapter 2,chapter 3).

In the ambiguous word learning situation presented here, children's assignment of the novel label to one of the two objects was modulated by one of our interest measures, namely looking time: As evidenced by their performance in both learnt label and supernovel label trials, children assigned the label to the object they looked at longer during the learning phase, when both objects were presented side-by-side. We found no evidence for a modulating effect of category arousal or object arousal – as indexed by changes in pupil dilation – on referent assignment, although these measures have been shown to modulate word learning and retention in unambiguous learning situations in similarly-aged children (chapter 2,chapter 3).

Crucially, the looking time measure, unlike the two pupillary interest measures, directly pits the two novel objects against each other and thus constitutes a relative measure of interest in the given situation – children make an active choice of one object over the other, whereas pupil dilation was measured independently for each object and did not tap into children's relative preference. When children see the two objects side-by-side in competition, longer looking determines their assignment of the label to one of the two referents. Importantly, the learning phase, from which the relative looking time measure is derived, shows the child the same object pairs that they see again in the word recognition phase. The test phase thus directly mirrors the visual experience in the learning phase. When the objects are presented in isolation one after another, as is the case in the arousal phase, interest as indexed by pupillary arousal does not modulate target assignment: Children's target looking remains around chance level in both trial types, indicating no preference for the assigned target over the distractor.

That children's interest as derived from relative looking time modulates target assignment becomes apparent not only in the learnt label trials, but especially in the supernovel label trials, in which children show a distractor preference after an initial brief look to the chosen target. It could be argued that children look at their preferred object in the learning phase as well as in the test phase and that children's increased PTL in the test phase only mirrors their visual preference from the learning phase. One way to control for this is by baseline-correcting PTL in the learnt label trials. Additionally, children's clear preference for the distractor image in the second half of the analysis window in the supernovel label trials further allows us to rule out a purely preference-based explanation of increased PTL in learnt label trials: Instead of looking longer at their preferred image regardless of the auditory prompt, children look at the object they have not yet assigned a label to when presented with a supernovel label. This performance in the supernovel label trials shows that children associate the previously unheard label with the object that is relatively more novel to them, consistent with the mutual exclusivity bias described by Markman (1990); Markman and Wachtel (1988): Once children have mapped a word to a referent and the referent becomes a known-name object, they will reject a second label for the same object. At the same time, children's tendency to associate the supernovel label with the less familiar object is in line with the novelty preference described by Horst et al. (2011) who found that children assign a novel label to the most novel object in a referent selection task.

Using head-mounted cameras to examine children's visual environments, Clerkin et al. (2017) proposed a new perspective on the puzzle of referential ambiguity. Clerkin et al. (2017) found that while the visual scenes that children encounter are indeed cluttered, the frequency distribution of objects is highly skewed, with certain objects appearing in the visual environment more frequently than others. Interestingly, there is a correspondence between these highly frequent objects and children's first-learnt words. These findings on the visual statistics of everyday environments highlight the importance of visual familiarity with an object for word learning. While Clerkin et al. (2017) examine the frequency distribution over a longer period of time, our findings point in a strikingly similar direction on a shorter time scale: Children are only exposed to the novel label and the two potential referents for a total of 30 seconds and 10 naming events, but their relative familiarity with one object over the other, determined by children's looking time, modulates their assignment of the label to one of the two objects.

In the present study, children are thus faced with an ambiguous situation that requires them to make an in-the-moment decision about a potential word-object mapping. While this differs from the long-term visual environment examined by Clerkin et al. (2017), both time scales play an important role in early word learning and are closely linked (Bion et al., 2013; Kucker et al., 2015; McMurray et al., 2012) propose that word learning involves both in-the-moment processes that support online referent selection, and long-term, associative processes that strengthen correct word-object mappings over time and prune incorrect associations. Crucially, in-the-moment referent selection is driven by competition between possible referents as well as domain-general attentional mechanisms (see also Kucker et al., 2015). The current study pits two competing potential referents against each other while also tapping into one such domain-general attentional mechanism, namely interest.

Our findings therefore allow us to combine these insights into the dynamic nature of word learning with recent approaches to curiosity- and interest-driven learning. While real-world visual statistics (and thus, looking times) and word learning situations are influenced by both the caregiver and the child, the present studies gave children the opportunity to impose their own structure on the learning environment: Children were presented with two competing referents and no further cues to the correct mapping between a word and an object. Both objects are thus equally likely to be the intended referent. What guides children's attention and determines which object they look at longer and subsequently map the label onto?

Accounts of curiosity in children highlight the importance of novelty in infants' curiosity-driven exploration: From early, broad descriptions of infant curiosity (e.g. James, 1899) to recent neurocomputational and robotic models (Oudeyer & Smith, 2016; Twomey & Westermann, 2018), the novelty of the stimulus is said to play a central role in attracting children's attention and guiding their exploratory behavior. In the present study, both possible referents were equally novel to the child in the sense that parents reported their children not to be familiar with either of the novel objects. Twomey and Westermann (2018) propose the concept of subjective novelty that takes into account the child's learning history and their current state of knowledge in a learning situation (cf. Mani & Ackermann, 2018, , for a review oft he role of prior knowledge): Children will sample from the learning environment in a way that maximizes learnability in a given moment, based on prior knowledge. Their attention allocation to the two pictures in the learning phase might thus be driven by the relative subjective novelty of either object for the learner. One measure of subjective novelty could be familiarity with the category to which the object belongs, in which case an object from a less familiar category might be subjectively more novel and thus provide highest learnability. Interestingly, we found that children's looking time in the learning phase did not correlate with either parent-reported category familiarity or parent-reported category size as measured by the proportion of known FRAKIS items from each category. The explanatory power of these measures could however be reduced due to the limited variability in parent responses and the fact that most children are at ceiling in the FRAKIS measure. While the current results thus do not directly support the importance of subjective novelty in the sense of Twomey and Westermann (2018), this explanation for children's increased looking can also not be ruled out at this point.

On the other hand, children's attention allocation is also driven by the perceptual salience of a stimulus, a quality that has been linked to both curiosity (e.g. Markey & Loewenstein, 2014) and successful word learning (Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006, but see Wildt, Rohlfing, & Scharlau, 2019, for a review). In a single-exposure word learning situation, children's curiosity might thus be driven more by the objects' directly observable perceptual features. While we did not pre-test the novel objects for differences in perceived salience, a comparison of visual features suggests that this might indeed be the case. In the animal/vehicle object pairing, most children spend more time looking at the slow loris, which is in line with previous research that showed a preference for animal stimuli over non-animal stimuli (DeLoache et al., 2011). The preference was even stronger in the food/furniture pairing where the majority of children looked longer at the pink mochi compared to the brown easel. This preference for brightly coloured objects links back to James' observation that "[n]ovelties in the way of sensible objects, especially if their sensational quality is bright, vivid, startling, invariably arrest the attention of the young" (1899, p. 72) and is echoed by recent findings that children prefer looking at visually "interesting" instead of "boring" objects in the absence of additional social cues (Wildt, Rohlfing, & Rączaszek-Leonardi, 2018).

Children's attention – a mechanism that has been identified as crucial to referent relection (Kucker et al., 2015) – might thus be guided by the object's novelty and salience. When two referents compete and there are no external cues to support one of two potential mappings, children are guided by their curiosity, which leads them to allocate more attention to one of the objects and, subsequently, attach the label to this object.

This also links back to the stages of interest development as proposed by Hidi and Renninger (2006) who distinguish (triggered and maintained) situational from (emerging and well-developed) individual interest. Triggered situational interest is characterized by a short-lived increase in attention triggered by a specific environmental stimulus. Over time, situational interest might evolve into individual interest, characterized by repeated engagement with an interest domain. Individual interest – as indexed by parental report and pupil dilation in response to familiar objects from a category – has been shown to influence novel word learning and retention in unambiguous learning situations (chapter 2,chapter 3). Interestingly, individual interest in a category as indexed by pupillary arousal does not predict target assignment in the present study. This finding further highlights the importance of in-the-moment referent competition to resolve referential ambiguity: When determining the correct word-referent mapping in an ambiguous learning situation, children take into account what they are interest in in the learning situation, not what they are interested in in general.

Our findings combine different approaches to early word learning and thus shed new light on the question of how children resolve referential ambiguity. In the present study, children map the word onto the object they looked at longer, corroborating the importance of visual familiarity in resolving ambiguity (Clerkin et al., 2017). At the same time, our findings add to the growing body of evidence that children structure their own learning environment: In the absence of other cues, children's looking times are driven by their relative situational interest in one object over another. Crucially, target assignments are not predicted by interest measures that presented objects individually. This supports recent accounts of word learning that highlight the role of competition in referent selection. Taken together, our results suggest that children take their interest into account when in-the-moment referent selection is not biased by external cues.

Chapter 5

General Discussion

5.1 Summary of Empirical Findings

Young children are avid word learners whose vocabularies grow many times over during the second and third years of their lives. While the overall pattern of vocabulary development remains relatively stable across languages, children show considerable individual differences in the compositions of their early lexicons. Historically, this variability has usually been explained in terms of the quantity and quality of the input that children receive. More recently, research on early learning and development has highlighted the role of the child as an active learner: Children are interested in particular aspects of their environment and preferentially attend to and learn from stimuli of interest. This influence of interest on early development has potential implications for our understanding of word learning and variability in the early lexicon: Word learning might be driven by the interests the child brings to the table, and differences in early interests might explain differences in vocabulary composition. Against this background, the present thesis aims to shed further light on the role of interest

Across three eye tracking studies, we investigated whether interest helps children form and retain new word-object associations and whether it guides children's referent selection in a referentially ambiguous word learning situation. In all three studies, we differentiate between the influence of interest in the novel objects themselves (i.e. *object interest*) and the influence of interest in the superordinate semantic categories, e.g. ANIMALS or VEHICLES, that the objects belong to (i.e. *category interest*). Previous studies (e.g. Begus et al., 2014; Partridge et al., 2015) have shown that intertest at the object level has a beneficial influence on learning and information encoding. As children form and differentiate categories early on (e.g. Eimas & Quinn, 1994), it seems plausible that a beneficial influence of interest could extend to the category level as well: Children who are more interested in ANIMALS might show more robust learning of a novel animal compared to a novel member of a category they are less interested in.

We used two measures to assess children's interest, namely pupillometry and parental reports. The pupillary measure capitalizes on the findings that changes in pupil dilation are reflective of internal arousal (Hepach & Westermann, 2016). Arousal, in turn, has been linked to interest (e.g. A. Smith, 1953; Wallerstein, 1954). We therefore cautiously interpret the pupillary measure as an index of interest in the stimulus. The other interest measure was administered in the form of a questionnaire in which caregivers were asked to rate their child's interest in and familiarity with the objects and categories used in the study.

In the first study, presented in chapter 2, we investigated the influence of object interest and category interest on novel word recognition in order to examine the role that interest plays in forming word-object associations. While word learning is a complex process operating on multiple timescales, an initial association between a novel word and its referent lays the foundation for successful word learning. If children in this task show word recognition, this is taken as evidence for a new word-object association being learnt. 30-month-old children were first presented with scrambled and clear pictures of familiar objects from four early-acquired semantic categories. Differences in the pupillary response to the scrambled and the clear picture were interpreted as reflective of arousal and, by extension, interest. We averaged changes in pupil dilation across all four familiar members of a category as our measure of category interest. This allowed us to assign high and low-interest categories for each child. Children were then exposed to one new word-object-association from each of the four categories. Again, we interpreted changes in their pupillary response between the scrambled and unscrambled picture as an index of interest, this time in the novel object itself. In the test phase, we tested children's recognition of the newly-learnt word-object associations using the intermodal preferential looking paradigm: Participants were prompted to look at one of two novel objects presented side-by-side.

Increased looking to the target object, i.e. the referent of the novel word, was interpreted as successful word recognition. Overall, participants showed more robust recognition of newly learnt word-object associations from high interest categories: Children who showed an increased pupillary response to e.g. familiar members of the ANIMAL category learnt the new word-object association from this category better than the one from a low-interest category. Additionally, we found that interest – as indexed by the pupillary measure – in the novel object itself also facilitated word recognition, although this influence was less stable than the influence of category interest. The two measures of interest modulated recognition independently of each other. Parental ratings of category interest modulated word recognition in a strikingly similar way to the pupillary measure, but the two measures were not correlated with each other. This study provides evidence for a beneficial influence of interest on the recognition of newly-learnt word-object associations: Children's interest not only in a novel object itself but also in the category to which it belongs modulates their word learning.

In the second study, presented in chapter 3, we used a similar paradigm to examine the influence of interest on the retention of newly-learnt word-object-associations. Retention has been identified as an important test of word learning, as this delayed recall requires the child to have formed a stronger association between word and referent as is the case in immediate recognition (Horst, 2017). Previous work on retention (Bion et al., 2013; Horst & Samuelson, 2008) showed that children younger than 30 months do not reliably retain word-object associations they were exposed to in a laboratory word learning task unless the salience of the target object is increased. Here, we ask whether interest can help strengthen the word-object association to the point that younger children show retention in a delayed retention testing phase. Using the same stimuli and interest measures that were used in the first study, we trained children aged 24 and 38 months on four new word-object-associations. In addition to testing their word recognition immediately after exposure, we also tested their retention with delays of five minutes and 24 hours. We found that 24-month-olds showed recognition and retention of words from high-interest categories right after exposure and after five minutes, but not after 24 hours. For the older age group, we found evidence of retention for words from high- and low-interest categories at all time points, with a limited beneficial influence of category interest on retention. Children's pupillary data and parental reports of interest were not correlated, but we found that parent-reported familiarity with a category modulated word learning. These results corroborate findings on the developmental trajectory of word retention, while further underscoring the role of category interest in learning and retaining new words. This adds to our understanding of the importance of interest on a longer timescale. Here, interest emerges as one of the factors that help children rapidly expand their vocabularies in the second and third year of life: As a child is more interested in a category, newly encountered word-object associations from this category are strengthened and retained over a longer period of time. Eventually, this might affect the shape and structure of individual lexicons and account for the variability we observe.

The third study, presented in chapter 4, investigated the influence of object interest and category interest on resolving referentially ambiguous word learning situations. In their everyday learning environments, children are constantly faced with referential ambiguity and have to determine correct word-referent mappings in cluttered visual scenes (Clerkin et al., 2017). By exposing children to a referentially ambiguous situation, Study 3 thus more closely approximates how children encounter words and their referents "in the wild". However, here we eliminated pragmatic, statistic, and social cues that children have been shown to use to resolve ambiguity. This allows us to examine the role that interest plays: Is children's referent assignment guided by their object interest or category interest in the absence of other cues? Children aged 30 to 36 months were, again, presented with pictures of familiar and novel objects from four categories while we measured their pupillary response as described above. In the next step, we exposed children to two novel objects side-by-side while only providing one novel label, creating an ambiguous situation in which children could assign the label to either of the two objects. In the absence of other cues, both objects were a priori equally likely to be the target. If interest, however, biases the child towards assigning the label to one of the objects, our interest measures allow us to identify which of the two objects is the more likely target for each child. Across three analyses, we determined the more likely target based on their category arousal measure, their pupillary object arousal measure, and their relative looking times to the two objects in the learning phase. In the test phase, children saw the two novel objects side-by-side and heard either the learnt label or a supernovel label. In the learnt label trials, we expected children to look longer to the identified target. Supernovel labels allowed us to rule out that children's target looking in learnt label trials was driven by visual preference rather than recognition: Increased looking to the name-unknown distractor in supernovel label trials was interpreted as evidence for an association being learnt. We found no evidence of children's category interest guiding their referent assignment, which is in contrast to the beneficial influence of category interest in chapter 2 and chapter 3. Object interest as indexed by pupil dillary arousal also did not guide referent assignment. However, we found that children were more likely to assign the label to the object they looked at longer during the learning phase, which was corroborated by their increased distractor looking in the supernovel trials. Longer looking to one of the two objects during the learning phase was interpreted as relative interest in one object over the other. In a learning situation that pits two referents against each other, relative interest guides referent assignment, while interest at the category level does not influence referent selection. This result highlights the role of selective attention in an online referent selection task: While word learning is shaped by interest at the category level, relative interest in the moment helps children navigate referential ambiguity in the absence of external clues.

The results of these studies underscore the importance of children's early interests in word learning at different timescales. Children's interests in the objects around them and the categories these objects belong to guide their online referent selection (chapter 4), help them form more robust initial word-object associations (chapter 2), and beneficially influence the retention of word-object associations over a longer period of time (chapter 3). Taken together, the three eye tracking studies point at a key role of interest in vocabulary development as one of the factors explaining variability in the early lexicon. In the following, I will discuss how these results inform our understanding of curiosity and interest in early development.

5.1.1 Commonalities and differences

Across all three studies presented in this thesis, we find a beneficial influence of interest on early word learning. However, the precise nature of this influence is dependent on the learning situation. In the first two studies, children were presented with an unambiguous word-object-mapping: Each novel object was presented in isolation, while the child heard the label across several naming events. In these unambiguous learning situations, word recognition and retention were found to be influenced mainly by children's interest in the semantic category to which the word belonged, as indexed by children's pupillary response to pictures of familiar category members. Evidence for an influence of interest in the novel object, as indexed by pupillary arousal, was less robust in Study 1. In the ambiguous word learning situation that children encountered in the third study, their referent assignment was guided by their looking time during the learning phase itself. Here, we found no evidence for an effect of category interest or object interest as indexed by pupillary arousal on online referent selection: When two possible referents are pitted against each other, children's relative interest in object over the other – as indexed by their relative looking time during the learning phase – in direct competition determines to which referent the label is assigned.

Both the pupillary measure and parental reports were used as indices of interest in our studies. However, we found discrepancies between the two measures: In Study 1, pupillary arousal and parental reports of curiosity modulated word recognition in strikingly similar ways, but the two measures were not correlated with each other. Echoing the findings of Study 1, neither of the two age groups showed a correlation between parent-reported curiosity and the pupillary measure in Study 2. In Study 2, parent reports of their child's familiarity with a category (but not parental ratings of their child's curiosity) was found to modulate children's word retention.

These discrepancies raise the question what the two measures – pupillary arousal and parental reports – are tapping into and how they relate to our theoretical understanding of curiosity and interest in early development.

5.2 Models of curiosity and interest

Children are naturally curious learners who explore their surroundings from early on. This observation goes back to Montessori (1914) and has been echoed by (Piaget, 1936). This exploratory behaviour is intrinsically motivated, i.e. independent of an outside reward (Oudeyer & Smith, 2016; Twomey & Westermann, 2018). Recently, there has been renewed interest in this tendency of infants and children to explore the environment: How do children leverage their natural curiosity to gain information from the learning environment and maximize learning?

While the phenomenon of curiosity has been described in the psychological literature for over a hundred years (cf. James, 1899, for an early account), the underlying mechanisms remain poorly understood (Kidd & Hayden, 2015). Descriptions of curiosity vary wildly, with no universally agreed-upon definition in the literature. Amidst this vagueness, some core components of curiosity have been identified: Curiosity has been characterized as a "drive state for information" (Kidd & Hayden, 2015) during which humans display heightened attention to stimuli in their environment and are more receptive to information that can be learnt from these stimuli. It has also been shown that higher levels of curiosity correlate with better information retention and recall in adults, highlighting the key role that curiosity plays in learning. This positive influence of curiosity on learning has been found in a number of studies with adult participants, using trivia questions or blurred picture paradigms (e.g. Berlyne & Normore, 1972; Fandakova & Gruber, 2021; Kang et al., 2009). The reported correlation between curiosity and enhanced learning goes together with accounts of curiosity that identify its main purpose as a motivator of learning and information gain such as the knowledge-gap theory popularized by Loewenstein (1994): Loewenstein (1994) theorizes that curiosity is the result of a perceived gap between the current and the desired level of knowledge and that curiosity drives the closing of this gap by acquiring new information. Additionally, curiosity has been linked to the reduction of uncertainty: Curiosity drives the acquisition of new information in order to reduce uncertainty and minimize prediction errors. This role of curiosity is echoed in the learning progress hypothesis (Oudeyer & Smith, 2016): According to this account, the learner will preferentially seek out information that will allow them to minimize prediction errors in the future.

While the learning-enhancing and uncertainty-reducing properties of curiosity have been reported in adults across numerous studies, the link are less clear in developmental populations. Young children will preferentially attend to stimuli of an intermediate complexity (Kidd et al., 2012, 2014) and stimuli that allow them to maximize information gain in a given learning situation (Poli et al., 2020), which speaks for an influence of curiosity on attention and learning even at an early age. However, Chen et al. (2021) found no evidence for a drive to reduce uncertainty in 8-months-olds, while learning was enhanced in a curiosity state. These mixed results suggest that curiosity in infancy and early childhood serves a broader attention-enhancing function. Taken together, curiosity in early childhood can be characterized as an intrinsically motivated state of heightened attention to a stimulus in the environment that leads to enhanced information encoding.

Related to the concept of curiosity is the concept of interest. Like curiosity, interest has been characterized as a motivator for learning (Ainley et al., 2002; Hidi & Renninger, 2006) with a beneficial influence on learning and attention (e.g. Hidi, 1995). Theories of interest distinguish short-term *situational* from long-term *individual* interests, a distinction captured in the four-phase model of interest development propsosed by Hidi and Renninger (2006).

The four-phase model of interest development argues that interest develops over time from situational to individual interest. The first phase of interest, *triggered situational interest*, is fleeting in nature: An external stimulus triggers a short-term response due to its novelty, surprise or personal relevance. Much like the first phase, the subsequent phase of *maintained situational interest* is externally supported. However, this phase is characterized by prolonged and/or repeated attention to a stimulus or a type of content. The next phase, *emerging individual interest*, on the other hand is self-generated: At this stage, children will seek out the type of content they are interested in and start to ask questions and store knowledge about their interest domain. Eventually, children might progress to the fourth phase of interest, *well-developed individual interest*. This stage is characterized by a positive attitude towards, increased knowledge of, and repeated engagement with the interest domain. While all phases of interest are characterized by heightened attention to particular stimuli, situational differs from individual interest in two main ways: First, situational interest is a short-term response, while individual interests are observed on a longer time scale. Second, and relatedly, situational interest is tied to an external stimulus that triggers the interest response, while individual interest is typically self-generated.

To date, most research on interest in childhood was done with older children: With its roots in educational science and educational psychology, interest research has mainly focused on school-aged children developing and maintaining interests in educational settings. The notions of situational and individual interest have been applied to academic domains such as writing (Lipstein & Renninger, 2006) or STEM fields (Drymiotou, Constantinou, & Avraamidou, 2021; Loukomies, Juuti, & Lavonen, 2015). On the other hand, little is known about the influence of the different types of interest on learning in early childhood before children enter a school setting. DeLoache et al. (2007) and Renninger and Wozniak (1985) provide some insights into interest at a younger age. The extremely intense interests examined by DeLoache et al. (2007) map onto – and go beyond – well-developed individual interests in the four-phase model: Young children are reported to repeatedly engage with their interest domain over a mean duration of 22 months, while showing an extensive knowledge of their chosen topics. This is in line with the work of Renninger and Wozniak (1985) who found that preschooler's individual interests – observed over a period of three weeks – modulated their attention and object recognition. Both studies corroborate the relation between individual interest, learning and knowledge that is also proposed in the four-phase model, but do not explore the role of situational interest in early learning.

5.3 Situational and individual interest in early word learning

What emerges from these accounts of curiosity and interest is the importance of timescales when looking at their influence on early learning: The four-phase model distinguishes fleeting situational interest – a response to an external stimulus and therefore short-lived by definition – from more stable, long-term interests. Curiosity, as a response to the environment, also operates on a shorter timescale. Over time, situational interest can develop into individual interests that remain stable over time. This is consistent with accounts of extremely intense interests (DeLoache et al., 2007) in early childhood. These interests go beyond the usual scope of individual interest: Children show intense repeated engagement with a particular content class over an extended period of time, to the extent that parents consider these interests remarkable. Children also reach a considerable level of knowledge about the interest domain, speaking for the close interrelation of interest and knowledge reported in the literature (e.g. Grossnickle, 2016; Hidi & Renninger, 2006).

Measuring curiosity and interest, especially in young children, has proven difficult, not least because the concepts themselves remain vaguely defined. In the three studies presented in this thesis, we employ two main measures to tap into children's category and object interest. First, we measured children's pupillary response to the presentation of stimuli, and secondly, we ask parents to rate their children's interest and familiarity in different categories. In Study 3, we additionally used relative looking time as a measure of object interest, in keeping with findings that people look longer at stimuli they are more interested in (Lang et al., 1993; Russell, 1975). We chose the pupillary measure as an index of interest because changes in pupil dilation are reflective of arousal (Hepach & Westermann, 2016), which in turn has been associated with interest (e.g. A. Smith, 1953; Wallerstein, 1954). Therefore, changes in pupil dilation are cautiously interpreted as an index of interest-related arousal: If children are more interested in an object, unscrambling the picture will lead to heightened arousal, reflected in a stronger pupillary response. Across the studies presented here, we find discrepancies between the pupillary measure and the parental reports of interest: In Study 1, the two measures do not correlate with each other, but modulate word recognition in a strikingly similar way. In Study 2, there was no correlation between parental ratings of interest and pupillary data either, but we found that parental ratings of their child's familiarity with a category modulated word retention. This raises the questions what these two measures tap into, how they map onto the different types of interest and how they relate to learning. The timescales of curiosity and interest as well as their proposed measurement counterparts are summarized in Figure 5.1.[1]

[1]Note that curiosity as discussed in this thesis refers to state curiosity, as opposed to long-term trait curiosity.

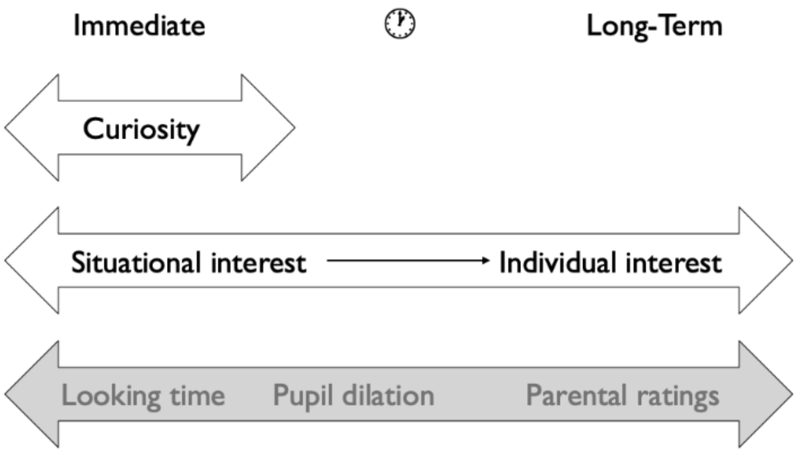


Figure 5.1: Timescales of curiosity and interest and their proposed measurement counterparts.

In order to assess children's interests in the categories and objects used in the study, we measured their pupillary response to scrambled and unscrambled pictures of familiar and novel category members. The relative difference between the two measures was taken as an index of interest. The pupillary measure captures the child's reaction to the presentation of a stimulus at a specific point in time. Pupillary responses reflect children's arousal (c.f. Bradley et al., 2008; Bradshaw, 1967; Hepach, 2017; Urai et al., 2017; Yucel et al., 2020), which we here interpret as an index of interest: If children are more interested in an object, unscrambling the picture will trigger heightened arousal and lead to an increased pupillary response. Averaging the pupillary response across all members of a category allows us to determine overall category interest. While their arousal to familiar members in a category is a momentary measure, it is nevertheless influenced by the associations that children have formed about the category members over time: Pupillary responses to familiar category members are averaged across categories and are reflective of children's interest in a given category at the moment of presentation, but are not independent of their prior experience with the category. Therefore, underlying interest in the category is likely to influence their pupillary response. This positions category interest (as indexed by pupillary arousal) between situational interest and emerging individual interest in the four-phase model of interest. Moreover, children's pupillary response to the novel members of the categories was interpreted as their situational interest in the given novel object at the moment of exposure.

In Study 1, we found that category interest modulates the recognition of a newly acquired word-object-association: Children showed more robust recognition of new word-object-associations from high-interest categories compared to those from low-interested categories. This study provides evidence for a beneficial influence of interest on learning that goes beyond the object level and extends to the category level: Higher interest in a given category leads to superior learning of new category members, independently of the child's interest in the novel object itself. The role of category interest in this learning situation fits with both the description of triggered situational interest and emerging individual interest in the four-phase model (Hidi & Renninger, 2006): The child's interest in the category is triggered by the presence of known members of the category and influenced by prior experience with the category, paving the way for a more robust acquisition of a novel word from the same category. Seeing the familiar stimuli leads to a state of heightened arousal, which in turn enhances attention and makes the child more receptive to new information, also keeping in line with accounts of curiosity that underline its attention-enhancing function (e.g. Chen et al., 2021; Kidd & Hayden, 2015). In addition to a beneficial influence of interest at the category level, we also found that interest in the novel object itself modulated learning, although to a weaker extent. The results of Study 1 thus corroborate findings that children retain information better that they are more interested in (e.g. Begus et al., 2014; Partridge et al., 2015), while also being the first to provide evidence for a role of interest – positioned between situational and individual interest – at the category level.

From research on extremely intense interests (Chi & Koeske, 1983; DeLoache et al., 2007) we know that children request information from the domains that interest them and can retain this newly-learnt information of a longer period of time, suggesting that interest in a category could beneficially influence not only the immediate recognition, but also the long-term retention of newly-learnt word-object associations. Indeed, Study 2 showed that the younger age group (24 months) showed improved retention of word-object-associations from high-interest categories, as indexed by their pupillary response to familiar category members. On the other hand, the younger age group did not retain word-object-associations from low-interest categories. These results shed light on the importance of situational interest on long-term learning: Momentarily enhanced attention stemming from children's higher arousal has an effect that goes beyond this specific point in time. These results also echo Horst and Samuelson (2008) who found that increasing the salience of target objects enhances retention of word-object-associations. In our study, interest in the category an object belongs to can be seen as a way to increase the novel object's salience, which in turn leads to more robust learning and retention.

In Study 3, the learning situation children were exposed to was different compared to the first two studies. In the third study, children were confronted with referential ambiguity: We presented participants with two objects while only providing one label. We examined whether children's interest played a role in resolving this referentially ambiguous situation. Again, we used their pupillary response averaged across four familiar category members as an index of their interest in natural categories. In contrast to the first two studies, we found no evidence of an influence of interest as indexed by the pupillary measure here: Their category interest did not guide referent assignment. Instead, we found that children's relative looking time to one object over the other in the ambiguous learning phase itself modulated referent assignment. Children identified the object as the referent of the novel word that they spent more time looking at during learning. This was shown in test trials using the learnt label as well as in mutual exclusivity trials that used a supernovel label. Their clear distractor preference in the supernovel label trials suggests that their looking behaviour in the test phase is not merely mirroring their visual preference from the learning phase but is driven by recognition. What is important to note here is that this learning situations involves two competing referents. As soon as competition between two referents is involved, we observe a shift in the role of interest: In the unambiguous learning situations in Studies 1 and 2, increased arousal triggered by familiar members of a category paved the way for successful acquisition and retention of new category members. Previous experiences and associations with known objects in the world came into play and guided learning. In the competitive ambiguous learning situation, however, these previous experiences and their potential to trigger interest do not help resolve the ambiguity. Instead, the child's direct preference for one object over another in the moment is what helps them structure the learning environment here. This study is thus more directly tapping into triggered situational interest as proposed in the four-phase model: In the learning situation, one stimulus triggers the child's interest more than the other, leading to increased attention and a bias to assign the label to the higher-interest object.

In this regard, Study 3 is closer to how children encounter words and objects in the real world: In everyday learning situations, children are constantly confronted with highly-cluttered visual scenes during which they have to map auditory input to objects in the environment (Clerkin et al., 2017). In our study, we reduced the visual clutter by only presenting two objects side-by-side, but left it open which of the two objects is the intended referent of the word, more closely mirroring word learning outside of the lab than in the other two studies. In a more ecologically valid scenario in which referents compete, situational interest in one of the two overrides other influences of interest: The properties of one of the two objects triggers the child's interest, attracting their attention in the learning phase. This eventually leads to referent assignment and later recognition.

The findings of Study 3 thus highlight the power of selective attention: Directing attention to parts of a cluttered visual scene is a powerful tool to resolve the uncertainty of word-object mappings in ambiguous situations. This is in keeping with research on the visual statistics of early learning environments and how children shape their own visual environments by selectively attending to certain objects over others: Research with head-mounted cameras (L. B. Smith, Yu, & Pereira, 2011; Yu & Smith, 2012a) reveals that children constantly structure their learning environment by creating situations in which one object is visually dominant, and that object labels presented during these scenes are learnt better than those presented in more cluttered scenes. Clerkin et al. (2017) provide further evidence for the importance of visual statistics in shaping the early lexicon: The frequency distribution of objects in everyday scenes is skewed, and children's first-learnt words correlate with the objects that children see the most. Here, our study adds to our understanding of the importance of visual environments and selective attention while also highlighting one of the ways that children impose structure on an unstructured environment in order to maximize learnability in a given situation: Guided by their interest, they selectively attend to one object in a cluttered scene and assign the novel label to this object of greater interest.

Across all three studies, we find evidence for an influence of situational interest or emerging individual interest on early word learning at different time scales. In Study 3, children are confronted with an in-the-moment referent selection task in the absence of other cues. Their situational interest in one object over the other guides their referent selection. In Study 1, emerging interest at the category level as well as at the object level helps children form an initial mapping between a word and an object. In Study 2, emerging category interest beneficially influences word retention after delays of five minutes and 24 hours, in keeping with the findings of Horst and Samuelson (2008) that increased salience of a target object enhances retention in 2-year-olds. We identified situational interest, as indexed by pupillary arousal and looking time, as a key contributor to referent selection, word recognition and word retention. This underscores the importance of interest even at an age that, to-date, has received little attention in the interest literature.

5.4 Parental ratings of interest

In addition to the pupillary measure, we asked parents to rate their children's interest in and familiarity with the categories and objects on a seven-point Likert scale. Interestingly, parental measures of interest did not correlate with pupillary data in Studies 1 and 2[2]. In Study 1, we found that the parental ratings of interest modulate word recognition in a strikingly similar way to the pupillary measure, despite the two measures not being correlated. In Study 2, we found that parental ratings of the child's familiarity with (but not the child's interest in) a category beneficially modulated retention in the younger age group.

These parental reports should be treated with caution as the parental data shows reduced variability in comparison to the pupillary data: The parents in our samples tended to rate their children as highly interested in most or all of the objects and categories presented in the studies, resulting in responses that skew highly to the right, i.e. the upper end of the Likert scale. Despite this reduced variability, I will discuss how the parental ratings might be reflective of children's interests in the following.

[2]The relation between parental and pupillary data in Study 3 remains to be explored further at the point of thesis submission.

When asked to rate their child's interest in a given topic in questionnaire form, it is likely that parents will base their ratings on their child's behaviour over a longer period of time in the past. Noticeable behaviours that are reflective of interest (according to e.g. DeLoache et al., 2007; Hidi & Renninger, 2006; Renninger & Wozniak, 1985) responses include repeatedly engaging with objects that belong to the interest domain (e.g. in the form of actual objects, toys, or media representations), talking about the interest domain, and requesting additional information, either non-verbally or by asking curiosity questions about the interest domain. This is also mirrored in the instructions given to the parents in the questionnaire. We therefore assume that parents take behavioural markers observed in the past into account when rating their children's interests. Here, the parental measure differs from the pupillary measure: While the pupillary data is a snapshot of children's arousal at the moment of exposure, interpreted as a proxy for their situational interest in an object or their emerging individual interest in a category, parental ratings are likely to be more reflective of long-term, stable interests. Within the four-phase model of interest development (Hidi & Renninger, 2006), parental ratings therefore map onto the later phases of interest, namely maintained individual interests. At the same time, we find significant correlations between children's reported category sizes (i.e. numbers of words known in a category according to the FRAKIS) and parental ratings of interest, suggesting that the number of words known in a category also serves as an observable proxy of interest for parents. On the one hand, this fits with models of interest that highlight the relationship between interest and knowledge (Grossnickle, 2016; Hidi & Renninger, 2006): Knowledge of a category and its members – reflected in the child's category size – increases alongside interest in the category. On the other hand, this also reveals a potential shortcoming of our parental measure. While increased category sizes could indeed be the result of sustained interest in the past, it could also be the case that parents conflate interest, familiarity, and semantic knowledge.

Parental reports and pupillary data do not correlate with each other, but have both been shown to influence learning and retention across the first two studies. As suggested above, the two measures are likely tapping into situational and individual interest at different timescales. In Study 2, we found no evidence of parental ratings of interest, reflective of more stable, long-term individual interests, influencing retention. At the same time, given our knowledge about extremely intense interests in early childhood (DeLoache et al., 2007), it seems unlikely that long-term individual interests do not influence learning.

At this point, it is important to take into account that word learning itself is a process that operates on different time scales, from online referent selection to long-term associative learning (Bion et al., 2013; McMurray, 2016; McMurray et al., 2012). The studies presented in this thesis look at word learning and recognition at a relatively short time scale: Studies 1 and 3 examine how children solve an ambiguous online referent selection task and how an initial mapping between a word and its referent is formed. Study 2 aims to tap into longer-term word retention by testing recognition after five minutes and 24 hours. However, all three studies exposed children to the novel objects for just 25 seconds and 10 labelling events, and we did not test even longer-term word retention after a week or a month. Shorter-term retention – at least up to the 24-hour delay used in Study 2 – was found to be influenced more by situational interest than by individual interest. However, real-world word learning operates on even longer time scales, with repeated exposures to the relevant word-object mapping that allow the child to prune incorrect associations over time (McMurray et al., 2012). Given our understanding of the relationship between increased interest and increased knowledge (Grossnickle, 2016; Hidi & Renninger, 2006) and parental reports of children's remarkable knowledge in the context of extremely intense interests (DeLoache et al., 2007), it seems plausible that a stronger influence of individual interests on (word) learning emerges when looking at timescales that go beyond what was examined in this thesis.

5.5 *Bagger* or *Bär*?

Why is early word learning ideally suited to look at the influence of interest on early learning at different timescales? Across three studies, we examined children aged two to three years: 24 months (Study 2, younger age group), 30 months (Study 1), 30-36 months (Study 3) and 38 months (Study 2, older age group). While work on extremely intense interests (Chi & Koeske, 1983; DeLoache et al., 2007) suggests that there are children as young as 18 months with stable long-term interests that, it can also be argued that in general, sustained individual interest is still developing at this age. From birth to adolescence, children's interests tend to become more focused, suggesting that interest is still rather malleable at age two to three and more readily influenced by the structure of the environment (Todt & Schreiber, 1998). This means that younger children might more often find themselves in situations where interest can be triggered by external stimuli and subsequently pave the way for more robust learning. The results of Study 2 also hint at this developmental trajectory of interest: Younger children only show retention for novel words from high-interest categories, while the influence of interest takes a subtler form in the older age group. By age three, children still benefit from category interest, but they have become expert word learners that retain newly-learnt word-object associations regardless of interest.

Across the entire life span, interest influences learning. However, interests become more focused and stable towards middle childhood, hinting at a greater fluidity in early childhood (Todt & Schreiber, 1998). This fluidity of interests in early childhood also provides parents and caregivers with a unique opportunity to influence children's learning. Word learning usually happens in interaction with a partner and has a social-interactive component (Tomasello, 1992, 2000). Pedagogical accounts of learning and development (Csibra & Gergely, 2009, 2011) highlight the role of the caregiver who provides structured input to the child. By altering their input, caregivers can actively create more opportunities for situational interest in a particular category to arise, thereby shaping both the child's interest and the child's vocabulary. At the same time, the results of the studies presented in this thesis underscore the role of the child themselves in the word learning process: The child will preferentially attend to the stimuli that interest them, taking the task of shaping the learning environment into their own hand. This creates a unique learning situation in which interest both influences learning and is (or can be) influenced by caregiver input.

Not only interests, but also the vocabulary itself is still developing – and rapidly expanding – during the third year of life. Children's word learning at this age can therefore be influenced by a number of factors that shape the size and composition of the early lexicon. At 24 months of age, we observe great variability with regard to the individual words known to children (Mayor & Plunkett, 2014) as well as the size and composition of semantic categories across children (Borovsky et al., 2016a). Most semantic categories are not yet saturated, and children constantly discover new category members that can be added to the lexicon. While interest has mainly been examined in older children in the past, word learning during the second and third year of life thus proves to be an ideal petri dish for studying the influence of interest on learning at an even earlier point in life.

These observations go back to the question what determines whether a child is a Bagger baby or a Bär baby. Based on large-scale data set of almost 15,000 children, Mayor and Plunkett (2014) show that there is a period of lexical acquisition during which expressive vocabularies show considerable individual differences, before eventually converging on a core vocabulary. Historically, these differences have mainly been explained in terms of differences in the input that children receive. Both the quantity (e.g. Hart & Risley, 1995; Huttenlocher et al., 1991) and the quality (e.g. Brent & Siskind, 2001; Cristofaro & Tamis-LeMonda, 2012; McRoberts et al., 2009; Schreiner, 2017) of language input directed at children have been shown to influence later language outcomes, including vocabulary size and structure.

The results of this dissertation add to our growing understanding of the key role of the child as a source of variability. These findings integrate with two lines of research: First, research on the role of the child themselves in word learning has identified various factors such as gender (Fenson et al., 1994; Huttenlocher et al., 1991; Hyde, 1981), birth order (Fenson et al., 1994), and temperament (L. Bloom, 1993; Hilton & Westermann, 2017; Slomkowski et al., 1992) as contributing to individual differences in lexical development. Secondly, recent research on curiosity-driven learning places the child in an active role and highlights how children shape their learning environments early on (Begus et al., 2014; Begus & Southgate, 2012; Kidd et al., 2012, 2014; Oudeyer & Smith, 2016; Poli et al., 2020; Twomey & Westermann, 2018): Children preferentially direct their attention in a way that helps them maximize learnability in any given situation. The studies presented in this thesis connect these two lines of research: We showed how situational interest at the object and category level facilitates the acquisition and retention of new word-object associations at different timescales. Interest is thus one way for children to impose structure on an unstructured environment: The enhanced attention that goes hand in hand with interest makes children more receptive to certain kinds of new information in the environment, increasing learnability from the stimuli of interest. This is in keeping with the theory of subjective novelty (Twomey & Westermann, 2018) and the learning progress hypothesis (Oudeyer & Smith, 2016): When directing their attention to stimuli in the environment, children take into account their current level of knowledge and chose the stimuli that provide maximized learning progress. By attending to stimuli from categories they are interested in, children select stimuli that fit with their prior experiences and knowledge while providing the opportunity to add a novel member to an existing category. Here, we can furthermore relate our results back to the findings of Borovsky et al. (2016a) who observed preferential attachment (cf. **?**, Barabasi1999)n word learning: Children more robustly learn from larger semantic categories by leveraging their existing semantic knowledge to learn a new category member. The category size at the moment of learning, however, might be reflective of their interests in the past, as suggested by the correlations between parental interest ratings and reported category size in Studies 1 and 2.

Across all three studies, we found a beneficial influence of situational interest on early word learning, in keeping with accounts of curiosity-driven learning. Interest was identified as a driving force behind referent selection, acquiring initial word-object mappings, and retaining them over time. Does this mean that interest alone explains the considerable differences we observe in early vocabularies and that we should discredit the role of input? We suggest that a comprehensive account of individual differences in early word learning and the resulting variability in the early lexicon has to be multifactorial. In the highly complex process of developing a lexicon, input, interest, and existing semantic knowledge are highly interconnected. Word learning is not an isolated process but happens in social interactions with caregivers or peers. At the same time, reports on extremely intense interests (DeLoache et al., 2007) suggest that caregivers are aware of their children's interests. This suggest a possible feedback loop between input, interest, and semantic knowledge that eventually shapes a child's early lexicon. As shown across the studies presented here, situational interest facilitates word learning. Over time, facilitated word learning in certain categories leads to differences in category sizes and overall vocabulary composition. Parents might then notice that their children show increased interest in certain objects and domains, and then alter their input accordingly. Providing more input from certain domains creates more situations in which situational interest can be triggered. Going back to the four-phase model of interest development (Hidi & Renninger, 2006), repeatedly triggered situational interest can over time develop into individual interest. Here, we see that interest at different time scales, caregiver input, and semantic knowledge constantly interact with each other and all contribute to word learning. This proposed feedback loop might also shed further light on the correlation between category size and parental reports of interest: While this could be explained as a conflation of interest, familiarity, and category size on the parents' side, it is not necessarily a shortcoming of our parental measure. Instead, the correlations underscore the interconnectivity of the different factors of influence.

To visualize this feedback loop, we can picture early word learning as a buffet Figure 5.2: Children can only learn from what is offered on the buffet (i.e. the input), but if parents notice that their child consistently prefers some parts of the buffet over others, they can alter the contents of the buffet accordingly by providing more of the input that the child shows more interest in. Parents can also keep track of what the child has taken from the buffet, i.e. the words they have added to the lexicon and the categories these words belong to. Across children, and for each child over time, the contents of the buffet will change based on the child's current preferences. As interests are still fluid in early childhood, parents can also influence what their child will pick from the buffet by altering the input.

5.6 Limitations and suggestions for future work

The results presented in this thesis add to the growing body of evidence for the importance of curiosity and interest in early word learning and show that early interest is a key contributor to variability in the early lexicon. At the same time, this thesis also raises a number of questions that remain to be explored by future research.

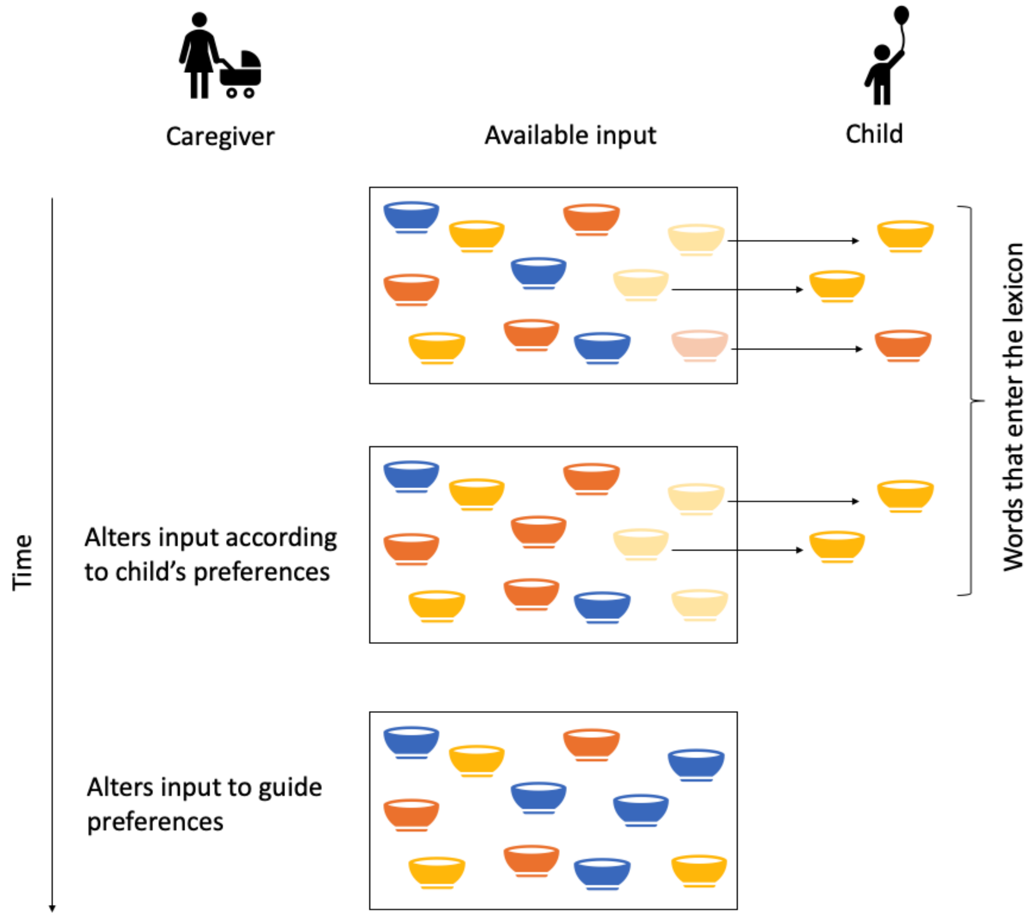


Figure 5.2: Word learning as a buffet: Children learn words from the available input based on their interests. Parents restock the buffet according to their child's interests, but can also influence interests by altering what is offered.

5.6.1 Category boundaries

In all three studies, we used familiar and novel objects that strongly suggested category membership by virtue of perceptual features. This approach is based on research showing that children robustly show distinction between basic-level perceptual categories in early infancy (Mandler, 2000; Mandler & McDonough, 1993), but eventually rests on the assumption that children's category boundaries coincide with adults boundaries. Across all three studies, category arousal was assessed based on predetermined categories, while children's actual category boundaries were not empirically validated. Future research should take into account that children might draw category boundaries differently, e.g. by adding a categorization task.

5.6.2 Interest, input and word learning across time

As the four-phase model of interest (Hidi & Renninger, 2006) suggests, interests develop over longer periods of time: Repeated triggered situational interest eventually leads to stable, long-term individual interest. The studies presented in this thesis merely present a snapshot of children's interest at one specific point in time. To a certain extent, this snapshot is reflective of children's interest development: As discussed above, parental ratings of interest and familiarity most likely take into account children's expression of interest in objects and categories in the past. A longitudinal study that follows children's interests and vocabulary development closely over the second and third year of live could shed further light on the flexibility and stability of early interests and their relation to word learning. Additionally, a longitudinal study would allow to examine the proposed feedback loop between children's interests and caregiver input: Do parents alter their input based on the child's (perceived) interests, and can children's interests be guided or changed by modulating the input? Answering these questions would shed further light on the interplay of the child and their caregiver in early language development.

5.6.3 Computational modelling

In the past decades, computational modelling has emerged as a third pillar in the study of early language acquisition alongside theoretical considerations and empirical investigations (cf. Bergmann, 2014). Computational modelling offers benefits in comparison to empirical research with developmental populations: Practical constraints limit the amount of data that can be collected from human subjects with regard to the number of trials, experimental conditions, and participants. Computational approaches let us model a large number of participants across different experimental conditions, while at the same time allowing us to fine-tune parameters. In a computational model, the effect of small changes to the parameters can be explored more easily than would be the case in an infant study. At the same time, computational modelling forces us to make assumptions about underlying cognitive mechanisms and processes explicit. As the precise mechanisms of interest and curiosity remain elusive (despite recent computational approaches, e.g. Twomey & Westermann, 2018), modelling interest-based word learning could advance our understanding of the underlying processes.

5.7 Conclusion

This thesis set out to shed light on the influence of interest on early word learning and the composition of early vocabularies. We examined to what extent word learning at different timescales, ranging from online referent selection to longer-term retention, is modulated by children's interests in objects and semantic categories. Across the three studies presented here, we find a beneficial influence of object and category interest on learning. These findings highlight the role of the child as an active learner who shapes their learning environment by selectively attending to and learning from stimuli in the environment. Interest-driven learning emerged as a key contributor to individual differences in early vocabularies, underscoring the role of the child as a source of variability. At the same time, the results presented here add to our growing understanding of interest in early childhood, an age group that has received little attention in the interest literature to-date.

List of Abbreviations

AOI	**A**rea **o**f **i**nterest
CDI	**C**ommunicative **D**evelopment **I**nventory
CFD/CFI	**C**uriosity as a **f**eeling of **d**eprivation / **i**nterest
EII	**E**xtremely **i**ntense **i**nterest
FRAKIS	**Fra**gebogen zur früh**ki**ndlichen **S**prachentwicklung
GCA	**G**rowth **c**urve **a**nalysis
LMM	**L**inear **m**ixed-effect **m**odel
LP hypothesis	**L**earning **p**rogress hypothesis
MBCDI	**M**acArthur-**B**ates **C**ommunicative **D**evelopment **I**nventory
PTL	**P**roportion of **t**arget **l**ooking
SES	**S**ocio-**e**conomic **s**tatus
WOA	**W**ord-**o**bject **a**ssociation

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Declaration of Authorship

Hereby, I declare that all parts of the dissertation were written independently. Assistance of third parties was only accepted if scientifically justifiable and acceptable in regards to the examination regulations, and all sources have been quoted appropriately. Parts of this thesis and some figures have been used in the following articles:

Ackermann, L., Hepach, R., and Mani, N. (2020). Children learn words easier when they are interested in the category to which the word belongs. *Developmental Science*, 23(3): e12915.

Ackermann, L., Förster, M., Schaarschmidt, J., and Mani, N. (subm). The Role of Interest in Young Children's Retention of Words. Submitted to *Child Development*.

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Publications[3]

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Ackermann, L.*, Lo, C.H.*, Mani, N., & Mayor, J. (2020): Word learning from a tablet app: Toddlers perform better in a passive context. *PLOS ONE*, 15(12), e024051. doi:10.1371/journal.pone.0240519

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Mani, N., & **Ackermann, L.** (2018): Why do children learn the words they do? *Child Development Perspectives*, 12(4), 253-257. doi:10.1111/cdep.12295

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