Laura Rose Colosimo

100146513

Visual Dynamics of Cross Situational Word Learning, Object Perception, and Discrimination

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School of Psychology, University of East Anglia

Abstract

In order to learn a new word, young children must bring together processes of visual attention, visual looking and learning, visual binding of what is where, and processes for coordinating, forming, and updating of word-object links across multiple presentations. Recent research has explored the problem of word learning via a cross situational paradigm because it enables researchers to investigate how children learn words in the context of ambiguous presentations of multiple words and objects extended over time. More recent research has begun to explore the mechanisms at work to support successful word learning in these experiments. Through manipulations of word and object orders, research has shown that memory and attentional looking are vital components that support word learning. The aim of this thesis is to use novel stimuli with tightly controlled visual properties to better understand the process of word learning in a cross situational paradigm. Overall, the results support two perspectives into cross situational word learning; one of gradual learning through attentional looking and association building and one of preferential object driven looking (familiar/ novel). These findings were replicated across all three of our cross situational studies regardless of procedure and stimuli. Although our stimuli with tightly controlled visual properties were difficult to discriminate, we do not believe they are the sole cause of our failure to find word learning in children as a group. As our experiment on object discrimination, found that participants were able to discriminate between the stimuli. Rather we believe our failure find overall learning in the cross situational word learning task, despite three near replications, suggests that this paradigm may not support robust word learning in infants. Thus, we conclude that there is need for more investigation into how individual differences in looking dynamics, over the course of training may influence later word learning.

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Chapter 1: Introduction

The complexities of word learning

Word learning is a complex process that is connected to multiple behaviours, aided by various cognitive and perceptual processes, and that develops over time. It can be especially hard for young children who have developing cognitive and motor systems and relatively little experience with their environment. To fully understand the complexity, imagine the day-to-day experiences of a child and their caregiver. While on a walk, a 12-month-old child and their caregiver pass a yard that has Easter decorations set up. In this yard there are brightly coloured eggs spread about, pictures of carrots and flowers, and an Easter bunny. The caregiver points to the yard and says, "Oh wow! Look an Easter bunny and eggs!" The next couple of days the pair walk past the decorated house and each time the caregiver points to the yard and talks about what is there, "Look at the big carrot next to the bunny," "Wow there is a pink tulip and a pink egg," "Do you think the bunny will put some eggs out at our house?"

For the child to learn the new word "bunny," several things must occur. The child must find and visually attend to the bunny amongst the highly stimulating decorations in the yard. The child also needs to process the auditory stream from their caregiver and parse out the individual word: "bunny." And these two streams of information—visual and auditory—need to be coordinated so that the new word is mapped to the bunny rather than the carrot or tulip that are also present. Finally, to be able to demonstrate having learned the new word, the child must remember the mapping over time and retain the vital components to be able to point to the bunny when prompted with the novel name on the next walk. This scenario highlights how perceptual, attentional, cognitive, and memory processes contribute to, and make word learning such an interesting and complex phenomenon.

Despite this complexity, children seem to learn words with relative ease and surprisingly fast. Research has found children begin to show signs of word recognition as early as 6-months-of-age (Bergelson & Swingley, 2012), start producing words at 12-months, and continue to rapidly develop their vocabularies within the second year (Bergelson & Swingley, 2010). Other research has estimated that between 1 and 2 years of age, children's productive vocabulary increases by 300% (Fenson et al., 1994). To explain this apparent ease and the rapid pace of early vocabulary development, past research has focused on the particular mechanisms that help children overcome the challenges of word learning with a focus on biases or constraints that might limit the possible referents children consider for new names. For example, research by Markman found that when infants are learning new words, they are more likely to assume they refer to the whole object as opposed to its parts (e.g., whole object constraint, Markman, 1991). Likewise, they will avoid mapping a new word to an object they already know a name for (e.g., mutual exclusivity, Markman, 1988). In addition, other research has shown children will focus attention on novel objects within a complex scene and upon hearing novel word tend to select the novel object as opposed to a familiar object (disambiguation; Carey & Barlett, 1978; Bion, Borovsky, & Fernald, 2013; Horst, Samuelson, Kucker, & McMurray, 2011).

More recently, work has explored the problem of infinite referents; that is, the idea that any new word could refer to an infinite number of possible things in the world (Quine, 1960), through a closer examination of children's point of view during word learning. In 2008, Yoshida and Smith examined children's visual experience from the child's point of view. The children, 18- to 24-months, wore a small camera on a headband while they played in a naturalistic setting with toys and social partners. Yoshida and Smith found that even in a cluttered setting, children often have only one or two objects in their view at a time. Additionally, the analyses suggested that children often select a single object to attend to and position within view, thereby generating their own visual experience and overt shifts of attention. Comparatively, Yu and Smith (2012) found that due to children's short arms and small stature this leads to a limited number of objects within children's view.

In subsequent studies, researchers have examined the visual correlation of objects present from the child's viewpoint during naming events. Pereira and colleagues (2014) found that the more visually dominant an object was at the time a name was provided, the more often children were able to select the correct novel object when prompted later at test, indicating the object's label was learned. If the parent named an object while children were moving their head to shift their attention to another object, names provided by parents were less likely to be learned. It was also the case that sometimes parents did not name what the children are attending to. This led to shifts in attention to the named object, but also less than optimal learning situations, as children had to change from what they were attending to. These studies show that children's view is more limited and focused than previously presumed. Yet, it is children's sustained attention to objects during naming that limits the ambiguity of the naming situation and creates optimal visual moments for words to be heard and learning to occur (Yu & Smith, 2012; Pereira, Smith, & Yu, 2014).

Prior research investigating visual attention has noted that young children's attention is often stimulus driven such, where children change their looking based on movement or changes within the visual field, but predominately infants' attention is sticky (Colombo, 1995; Colombo, 2001; Hood & Atkinson, 1993; Hood, 1995). The increased stickiness of attention over time is proposed to be key in the development of sustained attention in early childhood (Richards & Cronise, 2000). Taken together with the findings from the head mounted camera studies, infants' sticky attention may be beneficial for word learning as it provides more opportunity to receive auditory input and for naming events to occur. In addition, this type of attention may benefit word-object mapping with regards to time. Research has shown that it takes time to bind a name to an object which requires a stable visual representation of the object (Fennell, 2012). As Pereira found, children that had one object in view during a naming event retained the word-object mapping better than if there was another object in the visual field. The sustained look creates more time for the word-object mapping to form indicating that the temporal duration in which word learning takes place is another important factor to consider for successful word learning to occur.

As reviewed above, word learning research suggests that mechanisms and biases can help simplify the task of children's word-learning, but also that word learning events in and of themselves are not as cluttered or ambiguous from the child's point of view as might have been thought. By studying how children attend to objects when hearing words, we can see how their sticky looking can lead to sustained visual attention, extending the time spent looking at an object so that a word is more likely to occur while attention is on the object, and thus increasing the opportunity for children to form a word-object mapping. This extension of attention is not only important for forming a word-object mapping, but also for retention of the mapping.

Several studies have shown that children are able to quickly form a word-object mapping or 'fast map' novel words to novel objects (Baldwin & Markman, 1989; Dollaghan, 1985; Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998; Heibeck & Markman, 1987; McGregor, Sheng, & Smith, 2005). This ability has been found in infants as young as 17-months of age (Halberda, 2003), with multiple novel items (Wiljinson & Mazzitelli, 2003), and 30-month-old infants have been shown to fast map as many as six novel names within a single experimental session (Golinkoff et al., 1992). However, additional research on fast mapping has suggested that following the initial fast mapping event is a period of slow mapping necessary for retention of the word-object mapping

(Swingley, 2010; Carey, 1978). During slow mapping children build on the word-object mapping created in the fast mapping event over repeated exposures leading to retention. The time needed to form and retain word- object mappings has been supported by research that has shown lower retention rates of fast mapped words in young children.

Horst and Samuelson (2008) tested children's ability to retain fast mapped words after a five-minute delay. In the task, children were presented with several known objects alongside an unknow novel object. The experimenter allowed the children to visually explore the objects before asking for a target object. The study was designed based on the idea of mutual exclusivity, for if the child knew the names of the familiar objects and asked to get a "modi" or novel worded object, they would choose the novel object, as the familiar objects already have corresponding labels. Horst and Samuelson found that 24-month-old children were able to learn the novel words in the referent selective task, but the children's retention of newly formed word-object mappings after a five-minute delay was at chance levels. Horst and Samuelson argued that the poor retention found for the novel words may be due to the competition created from the familiar objects in a referent selection task.

To further investigate how competition affected word learning Horst and colleagues (2010), designed a follow up study. They tested whether the number of objects present on a referent selection task or the number of competitor objects influenced 30-month-old children's ability to learn and retain fast-mapped names. The results suggested that although the number of competitor objects did not hinder children's initial word-object mappings, they did hinder retention, where only participants who saw few competitor objects were able to retain the words. Furthermore, results indicated that children had often split their attention across the all objects both novel and familiar. This research suggests that competition for attention can perturb word-object retention and that in order to learn and retain new word-object mappings, children need to spend more time and attentional resources focusing on the target.

In a similar study investigating word retention of fast mapped words, Kucker and Samuelson (2012) sought to expanded Horst and Samuelson's findings through a replication with the addition of a familiarization period prior to referent selection. In this study, children were familiarized with either the novel names or novel objects to be mapped prior to a referent selection task. Kucker and Samuelson (2012) replicated the finding that 24-month-old children also could not retain fast mapped words after a short five-minute delay. In addition, the results showed that children's familiarity with the objects, but not the words, affected the word-object link, where a more novel object can detract from word learning. These findings led Kucker, McMurray, and Samuelson (2015, see also McMurray, Horst & Samuelson, 2012) to theorize that children are able to form initial word-object mappings quickly but that this initial mapping must be revisited multiple times subsequently to create a mapping stable enough to support demonstrations of retention. Specifically, integrating the word-object mapping into memory requires time and multiple exposures.

Taken together, children's short arms, sticky attention, and slow mapping shows that word learning is still a very complex issue dealing with visual attention, stimuli influences, and extended periods of time. Any study of word learning needs to account for how infants attend to different objects in their environment, how they coordinate attention between visual and auditory streams, how time affects how the mapping is made and retained, and how the novelty and familiarity of objects influence attention to learn words. More recently, research has offered a way to understand these aspects of word learning, with the study of cross situational word learning. The design of cross situational word learning presents multiple words and objects in an ambiguous context such that the correct mappings can only be inferred via compilation of instances experienced over time. This paradigm allows researchers to investigate how children's attention and memory for word-object mappings change and develop over time.

Cross Situational Word Learning

Cross situational word learning proposes that children can learn the names of objects over multiple ambiguous exposures, despite moment-to-moment uncertainty as to the correct word-object mapping. In laboratory cross situational word learning paradigms, several novel objects are presented on a screen, accompanied by novel words. On the first presentation of the novel words and referents it is not clear which word corresponds to which object. However, after repeated presentations the co-occurrences between the objects and their referents becomes more certain as the referents will always be accompanied by the matching object.

In 2007, Yu and Smith, tested adult word learning in a cross situational paradigm. Participants were shown pictures of uncommon objects paired with pseudowords. Eighteen word-object pairs were tested in three conditions; 2 x 2 (where each trial presented 2 objects and 2 words), 3 x 3, and 4 x 4. The object position and word order were randomized, so position and order provided no indication of which object corresponded to which word. Over the course of training, participants saw and heard each of the word-object pairs six times. Following training trials, one word was presented alongside four objects and participants were asked to select the picture of the object named by that word. This test was repeated for all 18 words. Yu and Smith found that adults in all three conditions learned the words at above-chance levels with the smaller set sizes leading to more word learning. They argued that participants used the statistics of the co-occurrences between the words and the objects to build associations over the course of training and learn the correct word-object mappings indicated at test.

A year later, Smith and Yu (2008) tested whether 12-month-old children could similarly learn words in a cross situational word learning paradigm. Children were tested in a 2 x 2 condition with only 6 word-object pairings. During training infants were presented with 30 4-second training slides/trials. The slides presented two novel objects on either side of a screen and two novel words were spoken one after the other. At test one word was repeated while two objects were presented on the screen. Smith and Yu (2008) found that infants looked significantly more to the object that had most often appeared when each word was presented in training, suggesting that infants are also able to learn words in the cross situational paradigm.

However, the underlying mechanism that enables this learning is under debate. Currently, two theories have been proposed to explain cross situational word learning. Proponents of association learning suggest that participants track all possible pairings across presentations and statistically weigh the most frequent co-occurrences as the correct mappings (Kachergis, Yu, & Shiffrin, 2013; Yu, Zhong, & Fricker, 2012). In contrast, proponents of hypothesis testing suggest that when exposed to a novel word and multiple possible referents, participants create an initial hypothesis as to what the correct word-object mapping is and either revise or confirm that hypotheses when presented with further evidence (Trueswell et al., 2013).

Although both of these theories have support in empirical studies, it has also been argued that they cannot be distinguished at a mechanistic level because both use the same co-occurrence data and account for the same pattern of learning (Smith, Suanda, & Yu, 2014). Specifically, Smith, Suanda, and Yu argue it is this structure of co-occurrence data that enables learners to pick up on the regularities of the underlying correspondences through competition and mutual exclusivity, which allows the learner to weed out spurious pairings, but does not provide differentiating theoretical data. Smith, Suanda, and Yu

(2014) reasoned that a theory integrating processes of visual attention, memory, and novelty, as well as how each influence word learning, is needed.

The cross situational word learning literature has provided some insight as to what contributes to successful word learning events. Yu and Smith (2011) conducted a replication of the 2008 cross situational word learning study with the additional use of an eye tracker. This study followed the same procedure as Smith and Yu, 2008. Yu and Smith (2011) found that 14-month-old children had significantly more looking to the target object compared to the distractor object at test, replicating the original word learning findings. Analysis of children's moment-to-moment eye movements during training revealed that children who learned more words had distinctly different patterns of looking compared to children who learned fewer words. Strong learners had more stable eye movements with fewer, but longer fixations. This study suggested that children learn words through sustained attention to objects on individual training trials, which gave participants more time to hear and map the word onto the object.

To further investigate how attention influences word learning, Yu, Zhong, and Fricker (2012) set out test whether adults' attention to word-object pairs affects learning and what looking patterns over the course of training lead to successful word learning at test in a cross situational study. Their study was composed of three phases. The first phase served to familiarize the participants to certain objects before training and test, three objects were presented on a screen with the words, "Ready for test." Participants were then informed that they would be learning word-object mappings and given instructions for the task. The second and third phases followed the same procedure as Yu and Smith's (2007) 4 x 4 training condition where 4 objects were shown on a screen with 4 pseudowords spoken. The test was an 18- alternative forced choice test, where all objects were presented on the screen at once while names corresponding to the objects were played auditorily.

In order to systematically analyse word learning over the course of training, subjects were divided into groups based on how many words they demonstrated having learned at test. In the fine-grained eye tracking analysis, Yu and colleagues (2012) found that participants, as a group, attended equally to all objects on the screen with similar number of fixations and fixation lengths when no words were present. However, participants selectively attended to objects differently once they heard a word. After hearing a word, participants selectively shifted their attention between the objects and thus indicated the word-object mapping they were processing. This selective attention changed over the course of training, such that participants attended to objects they had previously looked to after a word was stated, if that object was currently present. If the previously attended object was no longer present on the trial, strong learners shifted looking to a novel (not previously attended) object, whereas weak learners continued to look at previously-attended-to objects. Over the course of training, strong learners were able to remember and retain information from previous trials and use that information to guide looking. This led strong learners to gradually build statistical evidence for the correct word-object mappings. Yu and colleagues contended that word learning requires multiple process including memory of the objects along with attention. Their findings reveal that word learners were able to control their attention after hearing a word and selectively attended to objects that they had begun to build an association for. In addition, strong learners were able to remember information from previous trials, such as learned word-object associations to guide attention to learn more novel word-object mappings.

An important finding to note is that strong learners often happened to look at the object that went with a given word at the start of training by chance. Thus, it could be that the difference between strong and weak learners was less a difference in learning ability between participants, but rather a difference in the luck of an initial look. By this alternative account, strong learners learned more words because over the course of training they had more opportunity to confirm and strengthen an initially correct word-object mappings, whereas weak learners had to overcome initially incorrect word-object. The results indicate that selective attention, as opposed to sustained attention, leads to greater word learning, suggesting that selective attention may develop over age as memory also develops.

Memory of objects has been shown to help adult participants learn word-object mappings, as they are able to use this prior knowledge to guide attention to form and learn words. In order to test how infants' attention and looking behaviour may be influenced by memory constraints of objects' familiarity and novelty, Smith and Yu (2013) repeated their 2008 cross situational word learning study but structured the training trials to test local familiarity and novelty effects in 12- and 14-month-old children. In addition, Smith and Yu used an eye tracker to track infants' attention over training. The order of the 30 training slides was manipulated such that each of the six objects were presented 5 times in a row in the same location over six blocks. Therefore, over the course of one block, a single word and object were presented in repetition with a more novel object and word. In contrast to previous findings (Smith and Yu, 2008; Yu and Smith, 2011), there was no difference in infants' looking to the target object and distractor object at test, suggesting that the local novelty effect disrupted overall learning. The data suggests that over the course of the training trials participants decreased their looking to the repeated objects and in turn increased their attention to the novel stimuli leading to less word learning. However, there were individual differences between children that led some to learn words (strong learners) while others did not (weak learners). A difference between strong and weak learners could be seen over the course of training; strong learners gradually accumulate to the novel stimuli and increased their looking to the repeated, familiarized stimuli, while weak learners continued looking to the novel stimuli throughout training. These results suggest that not only does novelty attract infants' attention, but it detracts from word learning. It was only the infants who were able to overcome this "novelty trap" and look to the repeating stimuli were able to exhibit word learning.

These findings appear to support the results of Yu, Zhong, and Fricker (2012), showing that attention to a more familiar objects led to greater word learning. Smith and Yu (2013) show that strong learners were able to overcome the novelty influence and shift their attention to the repeating stimulus which led to word learning. The research suggests sustained attention provides more opportunity to hear the word when looking at the right object, building up the word-object association. However, children who attend to the varying objects become distracted by the novelty and are not able to build up enough time with the objects and co-incident words to form the mappings. Therefore, these studies suggest that the ability to remember and attend to previously seen objects can strengthen word-objects association, while novelty can detract attention and perturb learning word-object mappings.

Vlach & Johnson (2013) sought to extend the research findings of Smith and Yu (2013) by testing memory contrasts on 16- and 20-month-old infants' cross situational word learning. The training trials were presented in block design consisting of 6 learning blocks, with half of the object-label pairings presented in immediate succession (massed) with the other half distributed across time (interleaved). The results showed that when the stimuli were presented in immediate succession both age groups were able to learn the pairings. However, only the 20-month-old children learned the word-object mappings when the trials were interleaved. The looking analysis revealed that 16-month-old children initially attended to objects presented in a massed fashion but over time selectively attended to the objects presented in an interleaved fashion. In other words, earlier in the experiment these children looked more to items that were presented repeatedly and thus more familiar from trial-to-trial, and later looked more to items that did not repeat often and thus were more novel. In contrast, the 20-month-olds did not differ in their looking to massed and interleaved objects. These results suggest that the 16-month-old children were not aggregating information from prior presentations. Vlach and Johnson argued this was due to novelty seeking behaviour in this younger age group, evidenced by their increase in looking to the interleaved object at the end of the learning block compared to looking to the massed objects in the first block of learning. The tendency of 16-month-olds to shift attention to the novel, interleaved object, resulted in these infants not building enough memory of the previously presented word-object mappings to show word learning at test. This study highlights not only the role memory plays in cross situational word learning, but how attention to objects that are relatively more familiar or novel may thus influence word learning.

Together the past three studies suggest that attending to similar objects over training leads to better word learning at test. Noting while adults are able to selectively attend to and remember these familiar objects, infants have a hard time disengaging from more novel objects in order to form and retain word-object associations. To further investigate how participants' selective attention may led to better word learning Kachergis, Yu, and Shiffrin (2013) allowed word learners to affect the structure of a cross situational word learning task through an active versus passive learning paradigm. In an active-learning condition, participants controlled what objects they saw and heard (named) on the next trial, whereas in a passive-learning condition, participants were given the trials a random set order with no repeating presentations. Kachergis et al. found that active learners performed better than passive learners; in addition, active learners who repeated multiple pairs per trial performed better than ones who repeated only one pair. Kachergis, Yu, and Shiffrin (2013) argued that the multiple presentations active learners gave themselves limited their working memory load by providing more processing to be allocated to form the word- object mappings. Essentially, by repeating multiple pairs with a previously unseen or novel pair they were able to practice the repeated pairs, while allowing learning for the new pair, engaging mechanisms like mutual exclusivity to aid in word learning. This work further supports the previous findings indicating that although novelty attracts attention, it subsequently detracts from learning since it does not provide repeated information that can help build word-object association.

Thus far research has shown that how participants attend to objects can affect their ability to learn words. Furthermore, when the order and presentation of the objects are manipulated adults will continue to attend to familiar objects, even when they can control the presentations, while children will attend to novel objects. Recent work by Roembke and McMurray (2016) has further examined how competition between objects affects word learning in a cross situational paradigm.

Roembke and McMurray tested adults' ability to learn 8 word-object mappings via a cross situational word learning paradigm with altered pairing presentations. Each trial presented three objects on the screen with one target word. At the end of each trial participants had to click on the object they believed corresponded with the word they heard. Over the course of training, each word had a target object (always present when the word was stated), a high co-occurrence competitor (that appeared on 60% of trials when the word was stated), and a low co-occurrence competitor (that appeared on 40% of trials when the word was stated). Participants' eyes were tracked over the course of the experiment to analyse their eye movements. Analysis of eye movements revealed that even when adults selected the correct target object on a trial, they still fixated on other objects more than chance suggesting adults maintain multiple hypotheses as to the correct word-object pairings over the course of training. Specifically, participants fixated the high co-occurrence competitor more, compared to the other objects, although this difference appeared within the later portion of individual trials. In addition, Roembke and McMurray measured the number of encounters with an object and found it to be a significant predictor of word-object mapping accuracy, suggesting that increased association leads to better word learning. This work brings the two theories, hypothesis testing and association, together, suggesting that both may account for how participants learn words. Although this work leaves the debate between the theories unresolved, it provides more insight as to how participants attend to objects in a cross situational word learning paradigm.

Initial research with the cross situational word learning paradigm confirmed that infants could learn novel word-object mappings via information compiled over multiple ambiguous naming instances. More recent manipulations of the paradigm and tests with participants of various ages have provided evidence of the mechanisms that support and strengthen word-object mappings, such as sustained and selective attention and those that detract from forming word-object mapping, such as objects' novelty and memory.

Outline of Thesis

Prior work using the cross situational word learning paradigm has provided insights into the necessity of coordinating visual and auditory attention, how novelty and familiarity of the referent object influences visual attention and suggests an important role for memory processes in shaping learning in this task. The aim of this thesis is to further explore the cross situational word learning task, detailing how children's growing representations of the objects are reflected in their looking dynamics, how these looking dynamics shape word-object mappings, and how the word-object mapping process builds over the course of training and test, so as to use this knowledge to boost children's learning in this task.

To achieve this aim, in Experiment 1 we sought to replicate the seminal cross situational word learning paradigm of Smith and Yu 2008 with the addition of looking measures during training and test. Our goal was to replicate their word learning findings and the sustained attention looking dynamics found in Yu & Smith (2011). Our one change from the prior study was the use of more controlled stimuli that varied metrically in similarity so as to enable manipulation of looking dynamics via changes in the objects in subsequent work. However, in Experiment 1, we were unable to find the high rates of looking during training or replicate the prior finding of word learning at test. We did, however, find similar patterns of looking dynamics to those found by Yu and Smith (2011) when we divided our subjects into strong and weak word learners. We additionally investigated participants' looking during training to objects that corresponded to words that they later showed learning for versus those they did not evidence having learned, which shed more light on how differences in the looking dynamics of strong and weak word learners might be related to learning.

Since we were unable to replicate in Experiment 1 the overall word learning found by Smith and Yu (2008), we decided to run another replication study with fewer methodological differences. In Experiment 2, we again did not find similar levels of looking during training or overall word learning at test and, further, we did not find a difference in looking dynamics between our strong and weak word learners. However, we did replicate our Experiment 1 finding of differences in strong and weak learners' looking throughout the course of training to learned and non-learned word-object mappings. This finding suggests that children look to all objects similarly (same fixation durations and number of fixations) over the course of training, but at test strong learners continue to look to objects they had accumulated more time looking at during training and weak learners switch to look at objects they spent little time looking at during training. Therefore, it is important to understand how these objects may have led to different types of looking, as well as both novelty and familiarity preferences.

Our objects are quite different from the stimuli used in Smith and Yu's studies and it is possible that this difference is affecting looking behaviour and word learning in our experiments. The individual stimuli we used share similar qualities that may not provide enough information for the infants to tell individual objects apart, garnering less attention and overall lower levels of looking, leading to poorer word-object mappings. Thus, we decided to examine the discriminability of our stimuli. We designed a novel test of infant discrimination and used it to systematically examine discrimination of our stimuli in infants from 12 to 30 months of age. To make sure the new methodology produced viable results, in Experiment 3a we tested adults. We found that adults were able to discriminate the objects and that their ability to discriminate systematically increased with larger changes in the stimuli. We then tested children in Experiment 3b. Examination of children's performance in terms of proportion looking for whole trials revealed that children's discrimination of the stimuli was far less robust than the adults' and was further influenced by their age, the degree of change, and the specific stimulus property that was changed. The overall pattern of findings was not systematic with regard to age, nor changes in the stimuli. Therefore, we reanalysed infant's looking data using a time course analysis to see how their looking changed over the trial. The time course data suggest that children were able to discriminate the stimuli, but that this ability was still variable depending on children's age, stimuli properties, and the degree of the change.

The data from Experiment 3 suggest that the stimuli we used for our cross situational word learning tasks in Experiments 1 and 2 were unlikely to be the sole cause of the low levels of looking and learning we found in those studies. However, we decided to rerun the cross situational word learning study using Smith and Yu' stimuli in an exact replication. In addition, we decided to not only use the traditional overall looking analysis but also the time course analysis used in Experiment 3b to get a more detailed view of children's looking during the test procedure.

Once again, we did not replicate prior findings in terms of overall word learning, nor the looking dynamics found during training in the Smith and Yu studies. We did however, replicate our prior finding of differences in strong and weak learners looking to the learned and non-learned words during training. The findings from the time course analysis emphasized how looking to the target object changes within the time course of the test trial. In particular, children look back and forth between the target and distractor, rather than just fixating the target (or distractor) for an entire test trial. This looking oscillation is potentially driven by preferences or even word learning developed during training, but also potentially driven more by intrinsic properties of a two-item preferential looking task. The general discussion integrates the findings from the four experiments and considers the evidence for whether infants are learning in the cross situational word learning paradigm or looking at test is driven by object preferences. Implications for future work and the problem with replicability are also discussed.

Chapter 2: Replication of Smith & Y, 2008 with Novel Stimuli

2.2 Experiment 1

The aim of Experiment 1 was to replicate the cross situational word learning findings of Smith and Yu. The original study conducted in 2008 had both 12-and 14-month-old children, however in 2011 Yu and Smith replicated these results only using the 14- month-old age group. Although the reason behind the choice to use only 14- month-olds in the later study was not stated, it may be due to the fact that 14-month-old children showed bigger and more reliable preference for the target than the 12-month-old children in the 2008 study. The 2011 study also differed from the 2008 study by adding additional analyses to investigate looking patterns that are related to better performance in this task. Because we wanted to replicate all of Smith and Yu's findings and because the 14-month-olds had such robust results, we decided to only use 14-month-olds for Experiment 1. In addition, we used novel stimuli with metrically controlled properties. These objects can be manipulated as to create objects that are very distinct in multiple properties or very similar within a certain property. Through different object manipulations we can further investigate how objects' properties can shift looking behaviour and possibly word learning. Lastly, we increased the test trial length by 2000 ms to 10000 ms see the full trajectory of looking throughout test, as well as the effect of words had on looking (Twomey & Westermann, 2016, Mather & Plunket, 2010).

2.2.1 Methods

2.2.1.1 Participants

The final sample included twenty-three 14-month-old infants (13 males, 10 females; 13.09-15.20) who were recruited from a Midwest college town in the United States through birth records. All infants were from middle class working families that spoke English more than 50% of the time. Sample size was pre-determined to be within the range of the prior studies, 27 and 18 14-month-old children for Smith and Yu (2008) and Yu and Smith (2011), respectively. In our study, an additional five children began the experiment but did not finish due to fussiness. An additional 11 infants completed the study but did not contribute data because either their average looking during the training trials was more than 2 standard deviations below the overall mean (5), or they demonstrated a bias to look to the right or left that was +/- 2 standard deviations of the total average looking to the right or left (6).

2.2.1.2 Stimuli

Six novel words were chosen from a list of novel words that follow English phonological probabilities and were recorded by a female speaker in isolation. Five of the six words were the same as those used by Smith and Yu's (bosa, manu, colat, kaki, and regli). The sixth word used by Smith and Yu (gasser) was currently used in another word learning study in the lab and was therefore replaced with gake. Six novel objects were created to have well-controlled metric shape and colour properties (see Figure 1). The shapes were composed of radial frequency components that provide even parametric neural spaces without category boundaries (Zahn & Roskies, 1972) and form a 360 degree space. The six stimuli shapes were sampled such that adjacent shapes differed by 60 degrees. Colours were also sampled from a 360 degree continuous colour wheel such that adjacent colours differed by 60 degrees (CIE Lab, 1976). Colour and shape were randomly paired to make 6 unique "beastie" objects. Eyes and legs were added to the objects to highlight their differences and to increase children's interest. The stimuli were presented on a 37-inch monitor with a white background. The words were presented over the monitor's loudspeaker. The beasties were between 8 to 10 inches in projected size, separated on the screen by 20 inches, and subtended an average visual angle of 16 degrees. This is the same visual angle of Smith and Yu's, whose stimuli size ranged from 12 to 14 inches, separated by 30 inches.

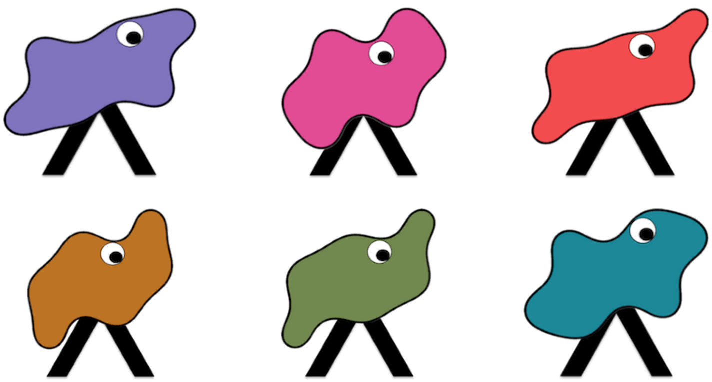

Figure 1. The six beastie stimuli.

2.2.1.3 Procedure

Infants were seated on their caregiver's lap 42 inches from the screen. Eye movements were recorded through a front view camera located at the base of the screen, directed up towards the infant. An additional back-view camera recorded the screen and captured what the infants saw. Caregivers wore blackout sunglasses to obscure their vision throughout the entire procedure and were asked to refrain from pointing to or otherwise or drawing their child's attention to the screen.

Similar to Smith & Yu (2008), on each of the thirty training slides, two beasties were simultaneously presented for 4000 ms. The first word was presented 500 ms after the onset of the slide. The second word was presented 500 ms after the offset of the first word. All six words were 1000 ms in length. Over the course of the 30 training slides, each of the six word-object pairs occurred 10 times. The right/left position and the order of the word presentation was randomly determined for each child such that there was no meaningful relation between the temporal order of the words or spatial position of the objects. In addition, the pairing of names and objects was randomly determined for each child. Each word-object pair co-occurred with every other word-object pair five times in the training trials. An attention grabber (picture of a Sesame Street character) appeared in the centre of the screen for three seconds before the start of the first training slide and every three slides thereafter to maintain attention. The entire training, 30 training slides and 10 attention grabber slides, lasted less than three minutes.

Training was followed by 12 test slides, which were presented for 10000 ms each. On each test trial two objects were presented on the screen but, unlike training, only one word, repeated four times, was presented. The object with which this word had co-occurred during training was designated the target. The other object served as the distractor. The distractor object was randomly chosen for each test trial. Each of the six words were presented twice. The left/right location of the objects, target and distractor, was counterbalanced.

2.2.1.4 Data Analysis

The front and back view camera recordings were time synchronized via DataVyu Coding Software (DataVyu Team, 2014). One coder segmented the back-view recordings into the 30 training slides and 12 test slides, additionally noting which object was on the left and right, as well as which word was presented first and second. Because these coders could have learned the word-object mappings over the course of viewing the experiment, they did not code looking direction. Rather, a second coder, blind to the correct pairings, categorized the direction the infant looked on each trial, frame by frame, as either right, left, or off. To check reliability, a random sample of 25% of the frames from both the front and back view recordings were coded by two additional coders. Coder agreement was

100% for trial time onset and offset, as well as position and identity of the beasties and 98% for direction of looking.

Data files extracted from Datavyu listed trial number, trial duration, objects, words or trial type (training/ test) and looking direction. Looking direction for both the training and test trials was subsequently classified as looks to the target, distracter, or off by matching the raw coding to the file used to generate the specific experimental session.

For data analysis, we ran a series of mixed-effects models using the lmer function in the linear mixed-effects package lme4 (Bates, Maechler, Bolker, & Walker, 2015) in R (R Core Team, 2016). Using mixed models allows us to estimate simultaneously, but separately, the main effects of different variables, as well as random effects. For variables with unequal variance we used the Welch correction.

2.2.2 Results

The purpose of this study was to replicate the cross situational statistical word learning results of Smith and Yu (2008) with the metrically controlled novel “beastie” objects. In addition, we were interested in investigating how looking during training relates to successful word learning (see also Yu and Smith, 2011). Thus, in what follows we first compare the descriptive data from training and test trials to Smith and Yu (2008) and Yu and Smith (2011), we then evaluate word learning based on looking time to the target and distractor at test, and finally individual looking dynamics during training and test.

Replication Results

Training Trials

On average, infants looked at the right and left sides of each training slide for equal durations. Preliminary data analysis indicated infants’ average total looking (sum of right and left looking) for the 4000 ms training trials was 3315 ms. Infants spent at least 1000 ms looking at each object on a training slide on 53% of the trials. They spent at least 500 ms looking at each object on 77% of the training trials. Smith and Yu (2008) found that infants looked an average of 3040 ms on training trials and looked to both sides (both objects) for at least one second on 87% of the slides. Thus, although our infants had a longer average total looking time than those in Smith and Yu’s study, they looked to both objects for 1s on fewer trials.

Test Trials

Infants looked at each 10000 ms test slide for an average total of 6814 ms. In comparison, Smith and Yu (2008) found that infants looked on average 6100 ms to each 8000 ms test slide. Overall, infants did not look longer to the target (3451 ms) than the distractor (3363 ms), $t(22)=0.70$, $p=0.49$, as can be seen in Figure 2. At the overall level, then, our results do not replicate the findings of Smith and Yu (2008; for a full comparison to Smith and Yu see Table 8 in Appendix).

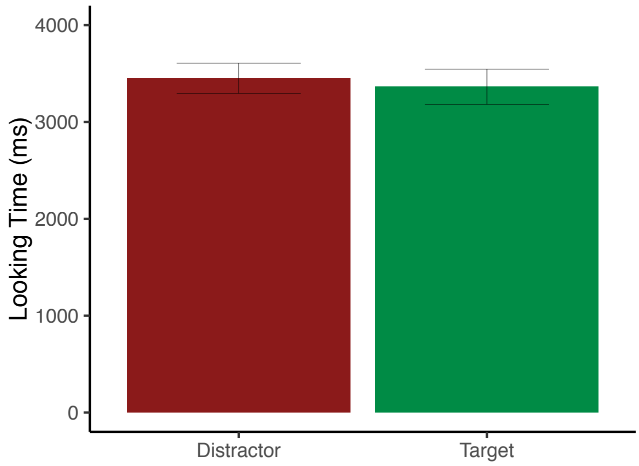

Figure 2. Mean looking time to distractor and target per 10000 ms test trial (and standard error of the mean).

In 2011, Yu and Smith replicated their previous findings of significantly longer looking to the target at test. In addition, they investigated infants' looking patterns during training in order to identify what contributed to successful learning. They did this by grouping children into strong word learners and weak word learners and comparing their looking dynamics during training trials. We followed-in with a similar analysis.

Training Trials Looking Dynamics

To examine how looking dynamics during training were related to successful learning, Yu and Smith (2011) classified children, not by how many words were learned, but overall looking more to the target or distractor at test. Those who spent more time looking at the targets were strong word learners, and those who spent more time looking at the distractors were weak word learners. Yu and Smith found that 12 of 18 children they tested were strong learners by this criterion. Using Yu and Smith's criterion, 10 of the 23 infants we tested were strong word learners. Our strong word learners looked significantly more to targets overall (3745 ms) than distractors (3270 ms), $t(9)=-4.87$, $p<0.001$ and showed longer looking to individual targets than distractors for an average of 3.6 out of 6 words. The other 13 infants, classified as weak word learners, looked significantly more to the distractor overall (3590 ms) than the target (3069 ms), $t(12)=5.38$, $p<0.001$ and showed longer looking to individual targets than distractors for 2.8 of 6 words.

With respect to training, Yu and Smith found that that strong and weak word learners did not significantly differ in their average looking time during training (M= 2960 ms for the strong and M= 3070 ms for the weak word learners). However, they did find a difference when they calculated average number of attention switches or fixations and average length of the longest fixation. Strong learners had fewer fixations (M=2.75) and a longer max fixation (M= 1690 ms), compared to weak learners who had more fixations (M= 3.82) and a shorter max fixation (M=1210 ms). Yu and Smith concluded that it was strong learners' sustained attention to objects during training that led to the learning demonstrated at test.

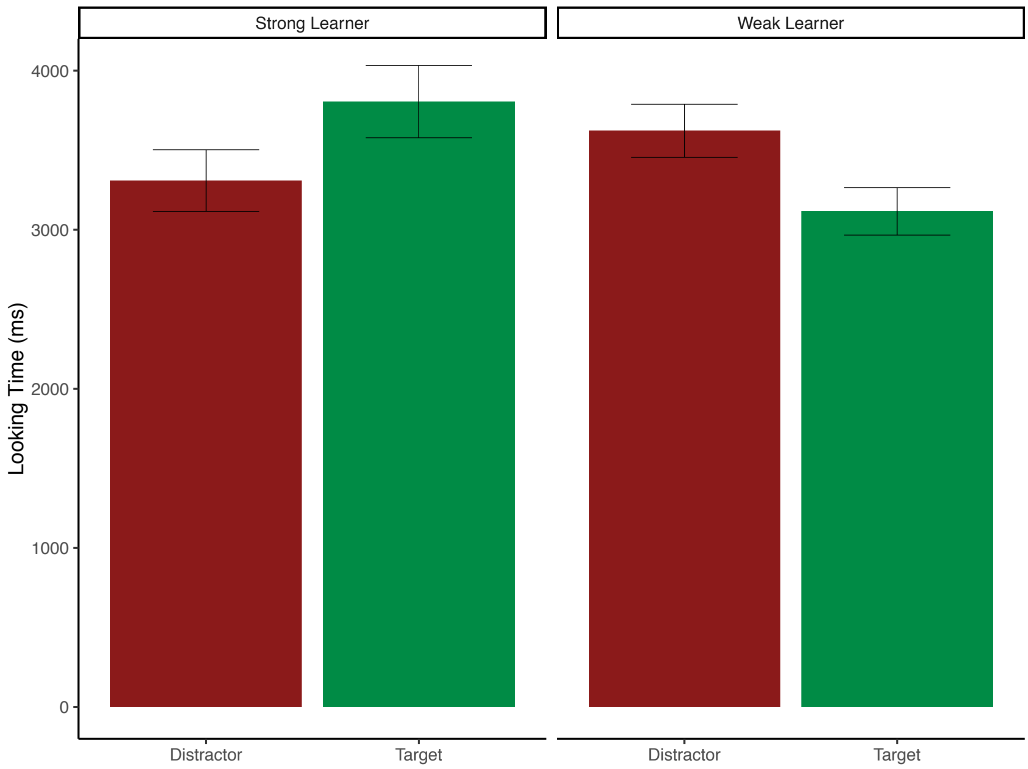

Figure 3. Strong and Weak Learner looking to distractor and target at test.

Similar to Smith and Yu, we found that the average fixation time during training did not differ significantly for strong and weak learners, strong learners: M=1418 ms weak learners: M=1271 ms, $t(18.92)=1.48$, $p=0.156$. Our strong and weak learners did differ in their longest fixation during training, strong word learners had significantly longer fixations (2261 ms) than weak learners (1984 ms), $t(20.91)=2.75$, $p<0.05$. However, there was only a marginal difference in the number of fixations, 2.58 v 2.90 for strong and weak learners respectively, $t(19.16)=-1.97$, $p=0.06$ (see Figure. 3).

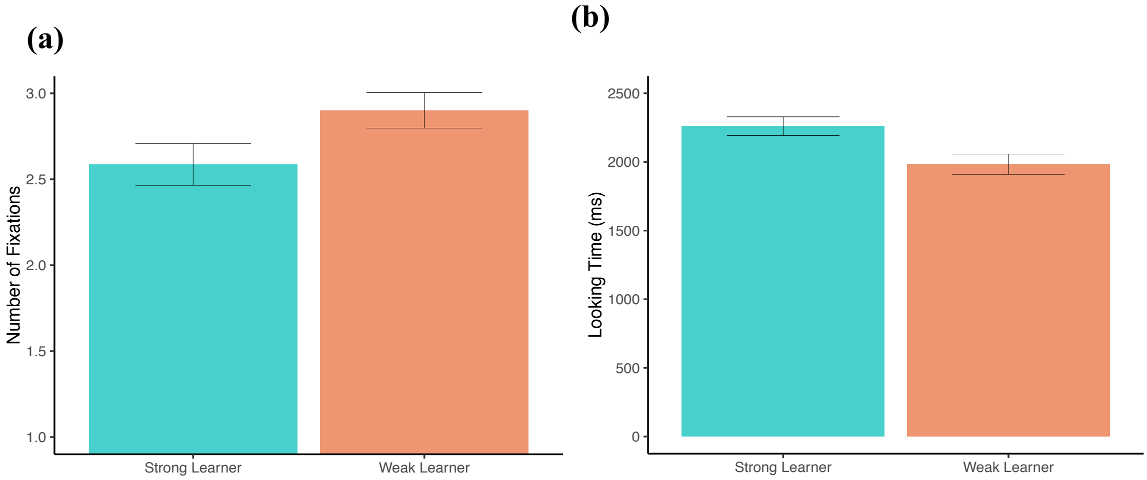

Figure 4. Looking dynamics during 4000 ms training trials: (a) Mean number of fixations for strong and weak learners (and standard error of the mean). (b) Mean length of longest fixation for strong and weak learners (and standard error of the mean).

We found some indication of a difference in looking dynamics for strong and weak learners during training, although it was not as pronounced as that found by Yu and Smith, and overall the looking dynamics of our infants are more similar to those of the weak learners in Yu and Smith (2011). Nevertheless, at the level of individual word-object pairs even the weak word learners showed greater looking to targets compared to distractors for some words. Thus, we next examined looking dynamics during training for words that infants later evidenced in test that they had learned and did not learn.

A word was marked as learned by an infant if average looking to the target across the two test trials was greater than average looking to the distractor. All six words were either marked as learned or non-learned for each participant. For each word, we accumulated the amount of time infants looked to the object that was its correct pair for each training trial. For example, if child X learned the words “bosa”, “gake”, and “manu” by correctly looking longer to the blue, green and magenta objects at test, we totalled all child X’s looking to the blue, the green, and the magenta objects (individually) across all the training trials. The average of these totals was child’s learned word looking. We did the same for the three objects child did not learn to get their non-learned word looking. Overall, we found that the average looking time to the correct object during training trials was slightly higher for words children later demonstrated having learned at test, however this difference was not significant, *M*=2073 ms for learned words, *M*=2014 ms for non-learned words, $t(22)=0.438$, $p=0.665$, see Figure 5).

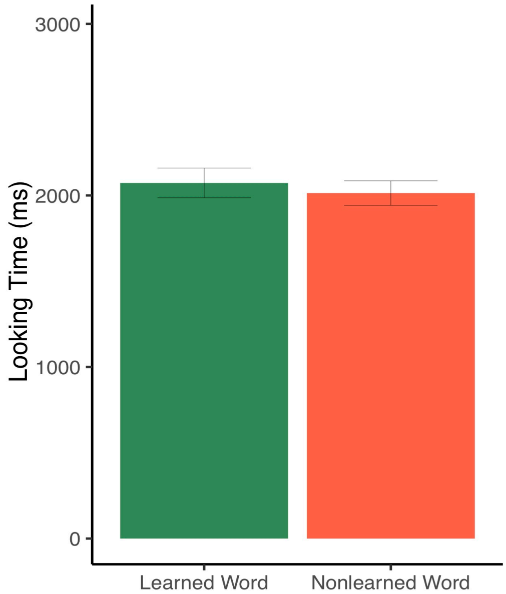

Figure 5. Mean looking to the correct object per 4s training trials for learned and non-learned words (and standard error of the mean).

Yu and Smith had found changes in looking dynamics over the course of the 30 training trials that were related to whether infants were strong or weak learners. Thus, we examined correct object looking by blocks of training trials for the strong and weak learners. This data set is presented in Figure 6. Note that all the data are looking to the correct object during training, but the green bars are for words for which at test infants looked longer to the object that corresponded to that word at test (our measure of learning), whereas the orange bars are for words infants looked longer to the distractor object at test. As is clear in the Figure 5, average looking to the correct object declines over training blocks for both strong and weak learners and learned versus non-learned word-objects. However, it is also clear that there is a difference in the strong and weak learners—strong learners have higher average looking to the correct object for their learned words from the beginning of training whereas weak learners have higher average looking to the correct object for their non-learned words from the beginning of training.

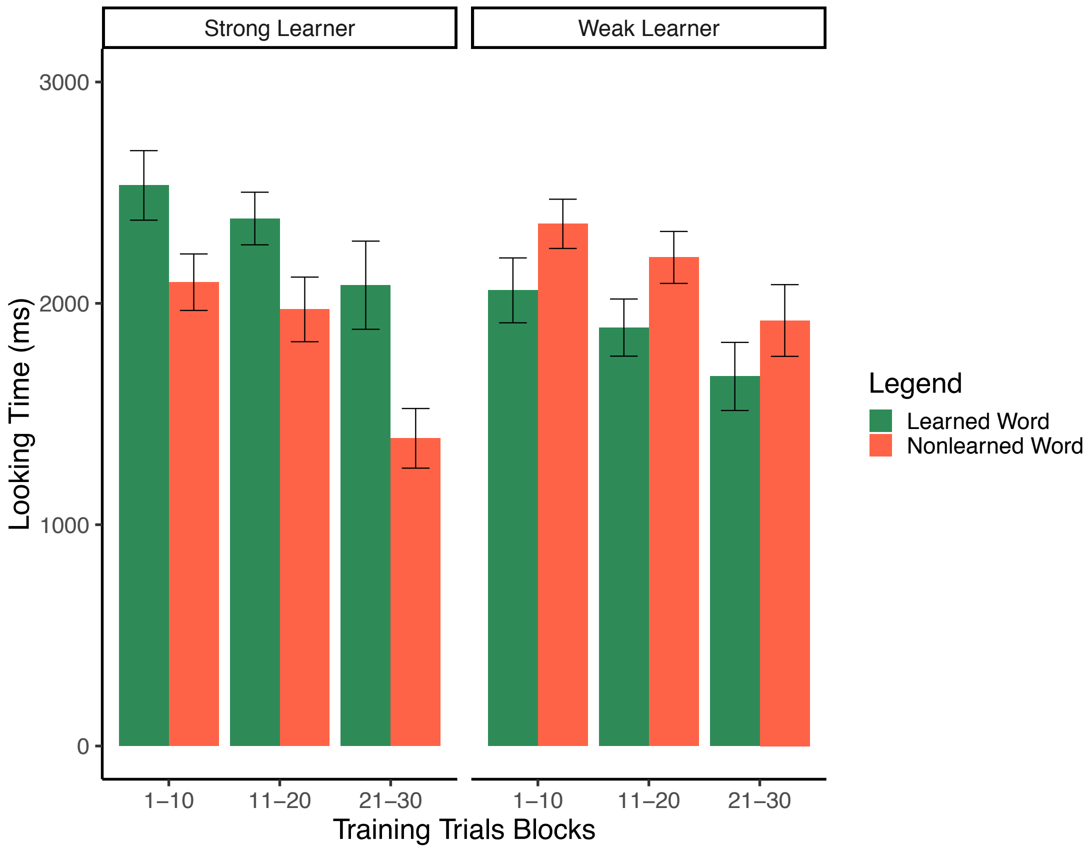

Figure 6. Mean looking to the correct object per 4s training trials for learned and non-learned words (and standard error of the mean) by strong and weak leaners.

This was confirmed with a with a mixed-effects model that included word type (learned and non-learned), learner type (strong/weak learner), and training trial block (1-10, 11-20, 21-30) predicting looking time. Likelihood ratio tests indicated that the best fitting random effects structure contained random intercepts for subject. The fixed effects justified by the data included a two-way interaction of word and learner type and a main effect of trial block. There was significantly more looking to the correct object on the first ten trials (1-10) than the middle ten (11-20), $t(115)=3.75$, $p<0.001$ and more looking to the correct object on the middle ten trials (11-20) than on the last ten (21-30), $t(115)=4.84$, $p<0.001$. These findings indicate that both the strong and weak learners look less to the correct object as training proceeded and suggests participants were habituating to these objects over the course of training trials.

The two-way interaction between word type and learner type was such that strong learners looked significantly more to correct objects during training for words that they would later demonstrate they had learned whereas weak learners looked more to the correct object for words for which they would later *fail* to demonstrate learning, $t(115)=4.99$, $p<0.001$. These results show that during training strong word learners spend more time looking at objects associated with words they later demonstrated having learned, whereas weak learners show the opposite, they look longer to objects paired with words they did not show learning for at test.

2.2.3 Discussion

Overall, we were not able to replicate the word learning found by Smith and Yu in our cross situational word learning paradigm. However, we did see similar looking dynamics for strong and weak learners; strong word learners had significantly longer max fixation length, but only marginally fewer fixations. Although we were not able to replicate overall word learning, the looking dynamics found in the strong word learners support Smith and Yu's claim that sustained attention leads to more word learning. Further examination of children's looking dynamics revealed that strong and weak learners have different attentional shifts from training to test for objects depending on if they correspond to a word that they learned or did not learn. Over the course of training both strong and weak learners habituate to the objects regardless of whether they were for learned or non-learned words and both strong and weak learners accumulated more looking time for some objects and less looking time for others. However strong word learners spent more time looking to objects that they would go on to show word learning for at test and weak learners spent more time looking to objects during training that they would go on to not show word learning for at test, and these differences in looking emerged within the first block of training trials. At test, then, strong learners continued to look to at objects that they accumulated more looking to over the course of training when they corresponded to the target word, weak learners instead shifted their looking to more novel objects that served as the distractor.

The looking dynamics suggests that sustained attention found in the strong learners' max fixation length and number of fixations leads to better word learning, supporting the findings from Yu and Smith (2011). However, the additional analysis investigating looking for learned and non-learned words may also suggest that strong learners may have learned more words by happenstance and preferences for previously attended objects. Strong word learners started looking to objects that they would go on to show word learning for within the first block. Yu, Zhong, and Fricker (2012) found that strong learners happened to select the target objects early in training. They argued that starting with the correct mapping allowed strong word learners to build up the correct associations during training, whereas weak learners, who happened to select the incorrect objects, needed more time to recover to show word learning at test. Our strong learners looking to the objects earlier on may have provided them more time to build the associations and at test, they were able to overcome possible novelty preferences and continue to look to these objects. Our weak learners did not necessarily look to incorrect objects, but instead spent little time over the course of training looking to objects that corresponded with words that would go on to learn, suggesting that their looking at test may be more driven by novelty than words. This implies that the differences between strong and weak learners may also be due to object preferences, specifically novelty and familiarity of the objects, as well as selective attention to these objects over the course of training. Preliminary analyses revealed no object effects, i.e. infants as a group did not show evidence of a preference for any one of the six objects during training or at test. Yet, it is still possible that individual children preferred particular objects and that these preferences, rather than learned word associations, drove looking behaviour at test. These results suggest the need for more investigation into infants' object preferences and attention to fully understand how children learn words in cross situational word learning.

In sum, like Yu and Smith (2011) we do see similar relations between looking during training and demonstrations of learning at test, suggesting that examination of visual exploration during training as a means to understand the process of cross situational word learning is promising. In particular, the fact that strong and weak learners show different patterns of looking from the first block of training and that these patterns are stable over training is very interesting. However, our failure to replicate the overall learning Smith and Yu found undermines strong conclusions. It is possible that this lack of replication is due to small differences in the experimental design. For Experiment 2 we modified our design to better match that of Smith and Yu (2008) in hopes of replicating the overall word learning and the looking dynamics found in the prior work.

2.3 Experiment 2: Replication with moving beasties

There were several small differences in the procedure of Experiment 1 compared to that of Smith and Yu: our objects were stationary whereas theirs jiggled and our test length was 2 seconds longer. There were also differences in the participants tested; Smith and Yu tested both 12- and 14-month-old children. Thus, we modified these aspects of our procedure in Experiment 2 and added a set of 12-month-old participants in a second attempt to replicate.

2.3.1 Methods

2.3.1.1 Participants

Twenty-four 12-month-old infants (10 males, 9 females) and 23 14-month-old infants (10 males, 10 females) were recruited from an East college town in the United Kingdom via community outreach and a laboratory registry. All infants were from middle class working families that spoke English more than 50% of the time. In our study an additional 23 children began the experiment but did not finish due to fussiness (12), equipment/experimenter error (9), and recruitment error (2). An additional 7 infants completed the study but did not contribute data because either their average looking during the training trials was more than 2 standard deviations below the overall mean (3), or they demonstrated a bias to look to the right or left that was +/- 2 standard deviations of the total average looking to the right or left (4). This number of children failing to complete or not contributing to analysis is slightly lower than Experiment 1 yet is still relatively high. There are several possible reasons for the high number of drops 1) we also increased our sample size to double that of Experiment 1, which could lead to a doubling of our drop rate, 2) we moved Experiment 2 to a new room in a new lab space, and the increase might be accounted for as growing pains leading to more technical and experimenter errors. These points notwithstanding relatively high drop rates are in not unheard of in developmental literature, nor within even cross situational word learning literature. Yu and Smith (2011) reported a drop rate of 30.4%, 14 drops out of 46 consented participants, Experiment 1 had a higher drop rate at 41%, and Experiment 2 reported drop rate at 38%.

2.3.1.2 Stimuli

The novel objects and words used in Experiment 2 were identical to Experiment 1. The stimuli were presented on a 42-inch monitor with a white background. The words were presented over the monitor's loudspeaker. The beasties were the same as in Experiment 1, between 8 to 10 inches in projected size, separated on the screen by 20 inches, and had an average visual angle of 16 degrees.

2.3.1.3 Procedure

The procedure was as described in Experiment 1 with the following three modifications to better replicate the procedure of Smith and Yu (2008). First, the beasties jiggled on every presentation in both training and test trials to mirror the movements in

Smith and Yu's experiment (Smith, personal communication, 2017). This modification was made to better match Smith and Yu's procedure, with the additional prospect of increasing children's looking to the objects. Second, we also created two set orders of trial presentation, as opposed to a unique order per child. The two orders had a different random pairing of words to objects. The randomization and counterbalancing of the order for both sets followed the same rules as in Experiment 1 and Smith and Yu; each object was presented equally often on both sides and paired with the first or second word presented an equal number of times. Third, the length of the test trial was decreased from 10000 ms to 7000 ms, closer to the 8000 ms used by Smith and Yu. The test trial was further decreased by 1000 ms as our overall looking times were lower and no pattern was revealed through the longer test trial length. Forth, the frequency of attention getters during test was increased to be between every test trial, as in Smith and Yu's study.

2.3.1.4 Data Analysis

Data analysis was identical to Experiment 1. Coder agreement for the back view was 100% and for the front view was 93%. It should be noted, however, that the back-view coder only coded trial start and stop times, as the two fixed orders were manually entered into the Datavyu coding software detailing the objects and words present for each trial.

2.3.2 Results

Training Trials

On average, infants looked at the right and left sides of each training slide for equal durations. Preliminary data analysis indicated average total looking for all 4000 ms training trials was 3190 ms for 12-month-olds and 3250 ms for 14-month-olds. Twelve-month-old infants and 14-month-old infants spent at least 1000 ms looking at each object on a training slide on 52% of the trials. Twelve-month-old infants spent at least 500 ms looking at each object on 75% of the training trials, and 72% for 14-month-olds. Overall, the average looking time was comparable to that found in Smith and Yu, however the percentage of looking to each side was lower for children in Experiment 1 than in Smith and Yu.

Test Trials

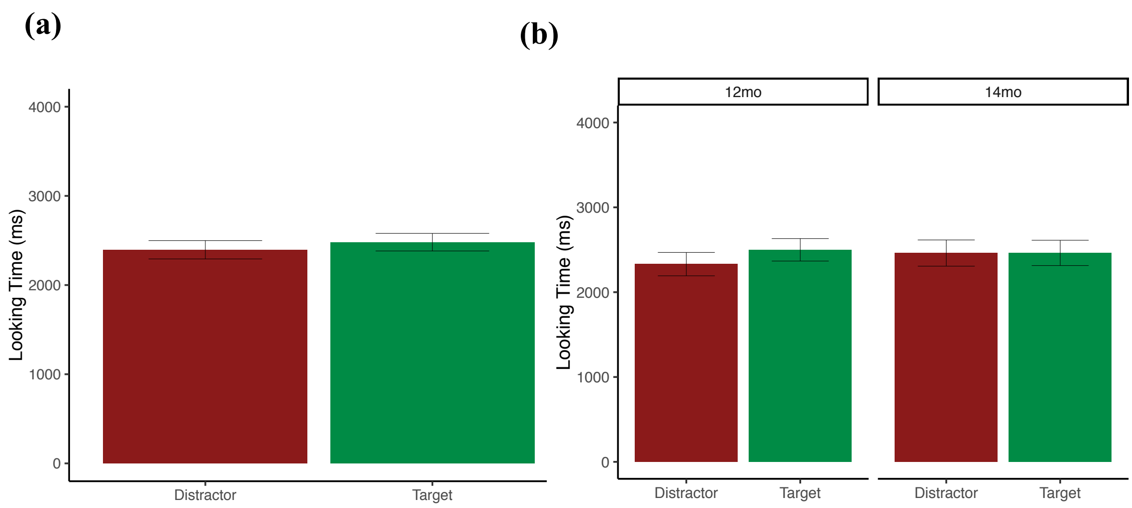

Figure 7. Mean looking time to distractor and target per 7000 ms test trial (and standard error of the mean). (a) 12 and 14-month-old combined, (b) 12- and 14-

On average, infants looked at each 7000 ms test slide for a total of 4877 ms. Overall, infants did not show a greater looking to the target (2481 ms) than the distractor (2396 ms), $t(45)=-0.91$, $p=0.366$, as can be seen in Figure 7. Furthermore, neither age group individually showed more looking to the target: 2499 ms v. 2331 ms (target v. distractor) looking for the 12-month-olds, $t(22)=-1.83$, $p=0.081$ and 2463 ms v. 2461 ms for 14-month-old (target v .distractor) looking, $t(22)=-0.01$, $p=0.992$; and (Figure 7).

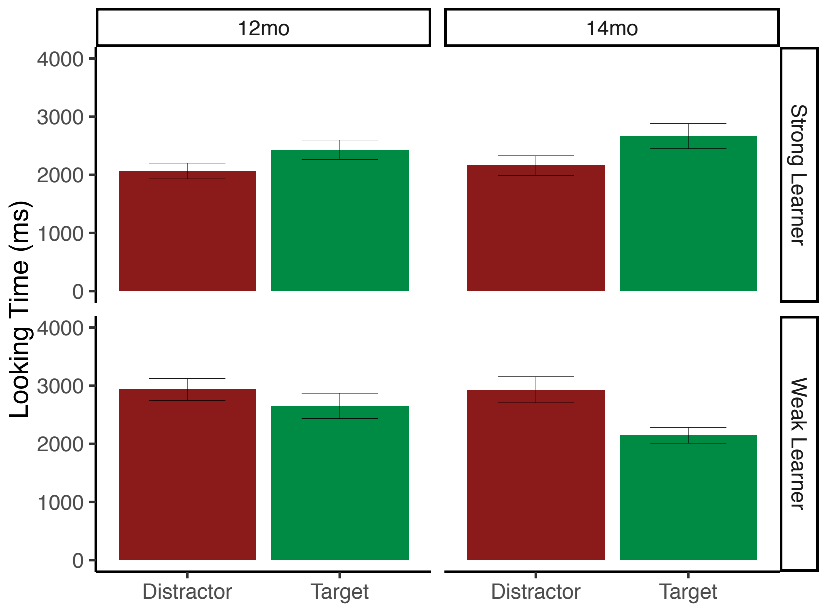

Figure 8. Mean looking time to distractor and target per 7000 ms test trial for 12 and 14-month-old strong and weak learners (and standard error of the mean).

Training Trials Looking Dynamics

The overall test-trial results suggest that the modifications to the procedure to better match the procedure of Smith & Yu failed to produce a replication of significant cross situational word learning. Nevertheless, we again separated the infants into strong and weak learners to investigate the looking dynamics during training. For the 12-month-old age group there were 17 strong learners and 7 weak learners. The strong word learners learned 3.19 words on average and had significantly more looking to the target (2432 ms) than the distractor (2066 ms), $t(15)=-3.98$, $p<0.01$. The weak learners learned 3.04 words on average and had significantly more looking to the distractor (2936 ms) than the target (2654 ms), $t(6)= 3.92$, $p<0.01$ For the 14-month-old age group there were 14 strong word learners and 9 weak word learners. The strong word learners learned 3.6 words on average and had significantly more looking to the target (2666 ms) than the distractor (2159 ms), $t(13)=-4.64$, $p<0.001$. The weak learners learned 3.3 words on average and had significantly less looking to the target (2147 ms) than the distractor (2931 ms), $t(8)= 4.61$, $p<0.01$ (see Figure 8).

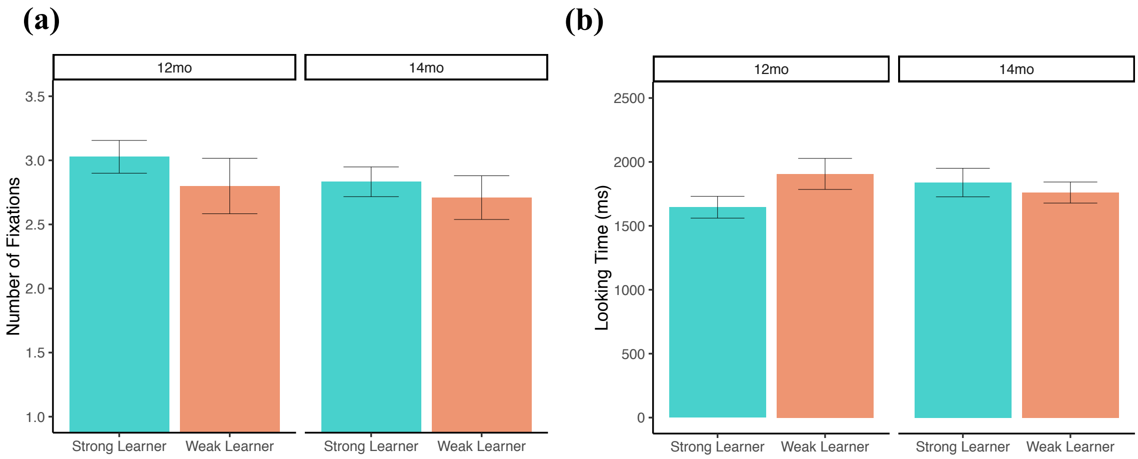

Figure 9. Dynamics of training trials looking for 12 and 14 moth-old strong and weak learners: (a) Mean count of fixations for strong and weak learners per 4000 ms training trial (and standard error of the mean). (b) Mean length of longest fixation for strong and weak learners per 4000 ms training trial (and standard error of the mean).

Next, we looked at the looking dynamics during training trials for the strong and weak word learners. The average looking on training trials did not differ between 12- and 14-month-olds: 1151 ms 12-month-old strong learners, 1367 ms 12mo weak learners, $t(9.64)=-1.93$, $p=0.083$; and 1323 ms strong learners, 1324 ms 14-month-old weak learners, $t(19.79)=-0.003$, $p=0.99$. There were also no significant differences in max fixation length for either the 12-month-old strong (1645 ms) and weak (1906 ms) word learners, $t(12.18)=-1.75$, $p=0.104$, or 14-month-old strong (1760 ms) and weak learners (1838 ms), $t(20.93)=0.56$, $p=0.579$. Finally, there were no significant differences in the number of fixations for either the 12- or 14-month-old learning groups, the 12-month-old weak learners generated 2.80 looks on average; the strong learners generated 3.02 looks, $t(10.42)=0.906$, $p=0.385$. The 14-month-old strong learners generated 2.83 looks and the weak learners generated 2.71, $t(15.11)=0.60$, $p=0.559$. Thus, our nearer replication of Smith and Yu's procedure failed to replicate the differences in looking dynamics they found and that we had some evidence of in Experiment 1.

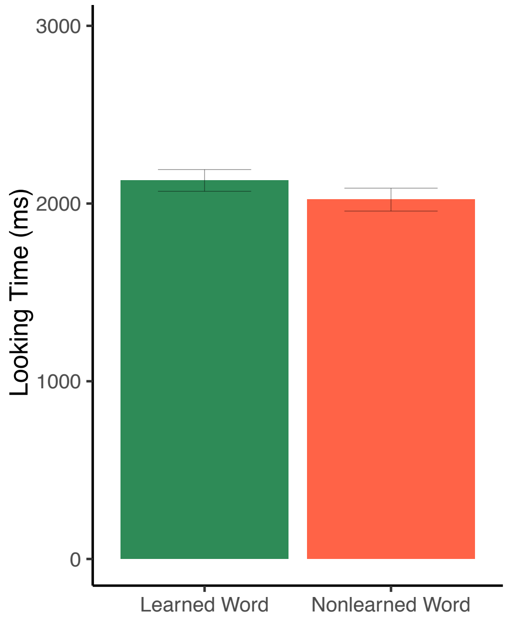

Figure 10. Mean looking to the correct object per 4s training trials for learned and non-learned words (and standard error of the mean).

As in Experiment 1, we also examined looking to the correct object for learned and non-learned words during training trials over blocks for strong and weak learners. For strong and weak learners combined, the average looking time to correct objects during training for learned words was moderately but non-significantly higher than non-learned words, M=2163 ms for learned words, M=2022 ms for non-learned words, $t(44)=1.35$, $p=0.1846$ (see Figure 10). We used a model with a full factorial combination of word type (learned and non-learned), learner type (strong/weak learner), and training trial block (1-10, 11-20, 21-30) to predict looking time. Likelihood ratio tests indicated that the best fitting random effects structure contained random intercepts for subject. The fixed effects justified by the data included a two-way interaction of word and learner type and main effects for trial block. There was a reliable main effect for trial block, with significantly more looking on the 10 middle trials (11-20) than on the last 10 (21-30), $t(221)=0.233$,

p<0.05. As in Experiment 1, this suggests participants looked less to the correct object over the course of training trials. There was also a reliable two-way interaction between word type and learner type with strong learners looking significantly more to the targets for what would be the learned versus non-learned words compared the weak learners, $t(223)=4.92$, $p<0.001$. Again, the lack of interaction with block suggests the possibility that infants who later show more learning of novel word-object mappings begin looking to targets more at the very start of the experiment, whereas weak learners look longer to objects paired with words they did not show learning for at test.

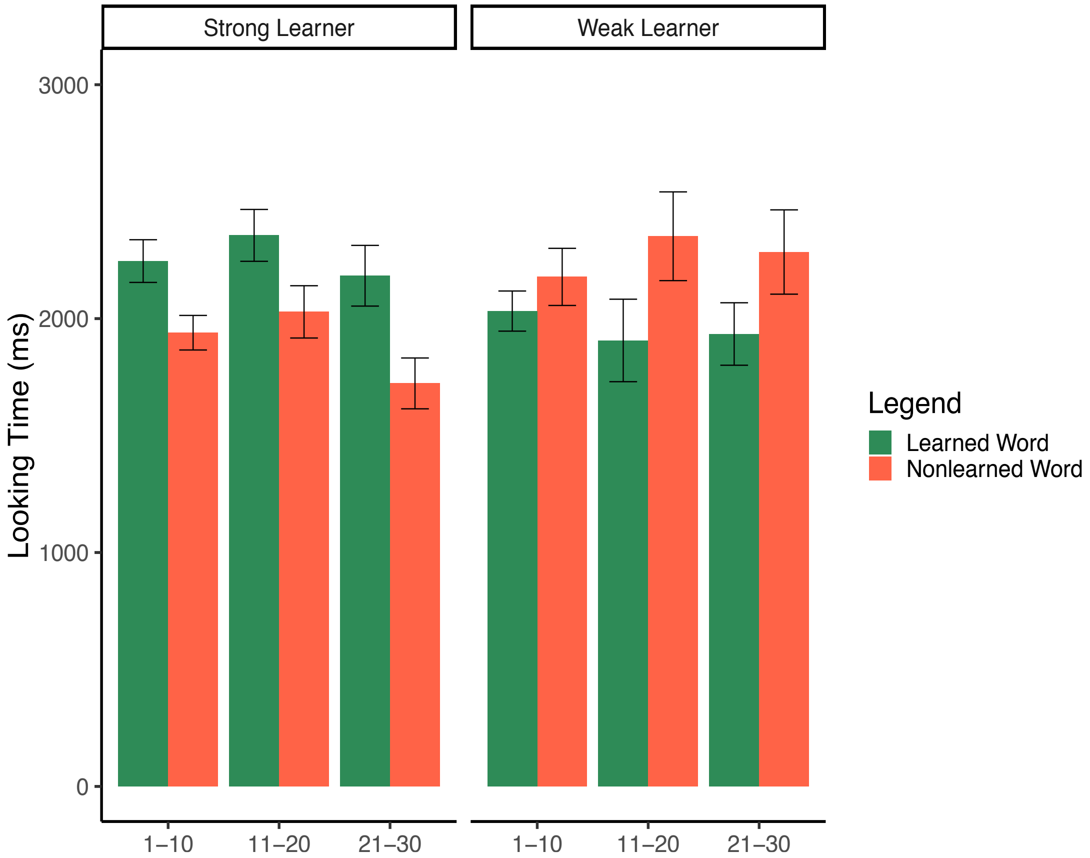

Figure 11. Mean looking to learned and non-learned words (and standard error of the mean) per 4 s training trial (and standard error of the mean).

2.3.3 Discussion

Experiment 2 was designed to bridge the differences in procedure between Experiment 1 and Smith and Yu's prior work to see if we could replicate the overall levels of cross situational word learning Smith and Yu found. Despite changing the images to jiggle during training, we did not find a significant increase in total looking time during training in this experiment compared to Experiment 1, Experiment 1 M= 3315 ms and Experiment 2 M=3196 ms, t(63)=1.45, p=0.152. Likewise, we did not find significant differences in looking to the target and distractor at test despite the shortening of the test trial length. Experiment 2 also did not replicate the strong/weak looking dynamics of maximum fixation length nor number of fixations found in Yu and Smith and Experiment 1. It did show similar word learning for strong learners and looking dynamics of learned and non-learned words for strong and weak learners. Together, the results from Experiment 2 may indicate that differences in fixation lengths and numbers of fixations between strong and weak learners might not be a robust predictor of successful learning. Rather, overall accumulated looking time to objects during training, as seen in our analysis of the learned and non-learned word looking results, might be more promising, as they replicated similar findings in Experiment 1.

Yu and Smith (2011) argue that long looks allow the children to hear the corresponding word and form the associations between the object they are attending to and the word. At test, the target word then promotes looking to the target object in a top down influence on word learning. Our results from infants looking to learned and non-learned word-objects from Experiments 1 and 2 may further support this argument. Although our strong learners did not have significantly longer max fixation lengths, they accumulated more looking time with the objects corresponding with the words they would go on to show they had learned. This additional time may help these infants to hear the corresponding words and form mapping. At test, the target word promotes their continual looking to the same objects. Thus, the continued looking to the same set of objects over the course of training and onto test that strong word learners demonstrate may be a different form of sustained attention to that of long max fixation and less fixation within individual trials. In contrast, weak learners also accumulate more looking to a set of objects during training. The difference is, they did not carry this visual attention on to test and instead start to look at the distractor objects that they have accumulated less looking to and are therefore more novel. In this way then, our weak learners are similar to the weak learners in Smith and Yu (2013) who seemed to get captured by the novelty of the varying objects.

An interesting issue is how it is that the strong learners happened to look at the right objects from the start. Strong learners look significantly more to the objects they will go on to show word learning for with in the first block, which continues throughout block 2 and 3. Weak learners on the other hand to not have a significant difference in looking to learned and non-learned word-objects until the second block and carries over onto the third block. Essentially strong learners may have gotten lucky or by happenstance looked to a set of objects in block 1 and may have picked up on the associated words. Over the course of training they continued looking to these objects building up the associations between the words and the objects. However weak learners may have started looking to incongruent word-object mappings. This resulted in them building weak word-object associations that they could not recover from and thus led to lower levels of word learning.

It is also possible that differences in children's looking to objects that correspond to learned and non-learned words is due to preferences for some objects over others. Preferences for particular objects could bias looking, in helpful or unhelpful ways during training, leading to the formation of correct (or incorrect) associations. However, preferences could also bias performance at test, and thus test performance may not indicate word learning. The strong learners continue looking to objects at test that they preferred to look at during training and weak learners switch their looking to more novel objects at test. This pattern of looking results in more looking to the target object for strong learners and more looking to the distractor object for weak learners. As we noted, it is possible that strong learners have learned the word-object mappings and at test their looking is driven by the target word, however, it may also be the case that strong word learners' early object preferences present as word learning and weak learners' object preferences present as poor word learning.

Research has shown that children often look to and prefer novel objects, which has been shown to help children learn new words (Kucker, 2014), while hindering word learning for others (Yu &Smith, 2013). The cross situational word learning task is designed in a way where all objects and words are presented for equal amounts of time during training and thus are all are equally novel and/or familiar to the children. Over the course of training children's attention to these words and objects should provide them with the opportunity to build associations or propose a mapping then then confirm or reject the proposed word-object mapping (hypothesis testing) over more exposures. Yet, when children do not attend to all objects equally and instead attend more to a subset of objects this leads some objects to be more novel and other more familiar regardless of the equal exposure time provided by the task structure. The results from looking to learned and non-learned words show that children are preferring and actively shifting their attention to a subset of objects indicating a preference during training. However, this looking preference is not driven by the objects, as there were no significant object effects, indicating that the looking toward the objects is driven by individual differences within the participants. It is possible that the difference between strong and weak learners is that weak leaners like novelty. After nearly 4 minutes of looking time accumulated to a set of objects weak learners became habituation to these objects and switched to look at the more novel objects regardless of target word at test, whereas strong learners carry their object preferences over to test.

These issues notwithstanding, there is one remaining difference between our study and that of Smith and Yu that might explain our failure to replicate overall and play into infant's demonstration of preferences for some objects over others--our stimuli. In particular, our beastie stimuli are far more similar as a group than the stimuli used by Smith and Yu. We saw habituation to the objects in Experiment 1, and overall, we are not getting as much looking as Smith and Yu. This suggests that the beastie stimuli might be too similar, which leads to less looking and might not generate the visual exploration necessary for word learning. The beasties are novel objects with metrically controlled properties, designed to be manipulated to test infant's attention. They were also designed to be as discriminable as possible with the largest degree separations for shape and colour—but these may not be enough for infants to discriminate them. Thus, in the next set of experiments, we asked what size of change in the components of the beasties are necessary for infants to evidence that they discriminate them.

Chapter 3: Object Perception and Discrimination in a new paradigm

3.1 Background of object discrimination

The results from Experiments 1 and 2 are concerning, in that we did not replicate the word learning found in Smith and Yu, nor did we find similar looking times despite our attempts to replicate key aspects of their methodology. However, we did find some levels of word learning in about half the children from both experiments and age groups. The looking dynamics found in both Experiments 1 and 2 indicate that children who show word learning at test, strong learners, and children who do not show word learning at test, weak learners, have similar looking dynamics (max fixation length and number of fixations) during training. When we analyse what words children learn at test, we see that their looking during training to these learned and non-learned word-objects differ. Over the course of training strong word learners look more to objects they show word learning for at test and weak learners look more to objects they do not show word learning for. The looking dynamics of the strong word learners lends support to Smith and Yu's hypothesis that sustained attention and looking during training leads to better word learning, as strong learners accumulated more time during target to objects, they would go to show word learning for at test, but does not refute preference driven looking.

Experiments 1 and 2, as well as previous cross situational word learning studies, highlight how important accumulating lots of looking time and long bouts of looking to objects over the course of training is for word learning. And the discrepancy in our results compared to those of Smith and Yu's is, aside from word learning, in overall lower looking times throughout our experiments. The design of Experiment 2 sought to increase infants' looking by jiggling the beasties and shortening test duration to reflect Smith and Yu's methodology. The results found in Experiment 2 instead indicated the same low levels of looking as Experiment 1 and further discrepancies between our results and those of Smith and Yu, as we did not find the difference they report between the strong and weak learners in max fixation length or number of fixations. Thus, here we investigate the properties of the remaining difference in our methodology—our stimuli.

The beastie objects were chosen as the stimuli for the cross situational word learning experiments because they afford the possibility of systematically manipulating their shape, colour and orientations in a continuous fashion. This would thereby allow us to create stimulus sets that we knew differed in specific ways, for example having colours that differed by 15 degrees. Once we replicated and identified how the looking dynamics contributed to word learning, it was our plan to then manipulate the beasties in ways to shift attention, increase or decrease object novelty, and ultimately lead to a better understanding of the word-object mapping process.

The specific six beasties used in our initial cross situational experiments were chosen to be maximally different in colour and shape with maximal, given the need for 6 objects, 60 degree separations on both dimensions for nearest neighbours. We made sure the beasties were around the same size as the novel objects used in Smith and Yu and maintained the same visual angle when presented in the experiments. However, one of the biggest differences between our beastie stimuli and the stimuli used by Smith and Yu is the overall similarity within the set beastie objects. Unlike Smith and Yu, whose objects were fairly diverse, the beasties all have similar features: cloud like bodies, rounded outlines, with legs and eyes. It is possible that despite the differences in colour and shape, the beasties were perceived to be from the same category and overall not distinct enough for children to map to six different words. It also may be that the features of the beasties were too similar to generate interest, attention, and thus the longer looking times needed for the formation of robust mappings. Thus, we decided to examine infants' ability to discriminate the colour and shape changes in the beasties. In addition, we decided to also look at discrimination of orientation changes in these same stimuli as that is the third dimension, we could have varied, in an effort to fully understand how children perceived and discriminated the beastie objects.

3.1.2 Review previous object and discrimination literature

Early research on infant object discrimination has found that young infants are able to discriminate objects with changes along various dimensions using simple paradigms that are based on same different judgements, habituation, and paired visual comparison. In one of the first studies to investigate infant object discrimination through generalized habituation, McGurk (1972) found that infants as young as 6 months of age can discriminate simple line drawings that change in orientation and form. Infants between 3 and 12 months of age, were habituated to objects that either held a constant form and orientation, a constant form with a variable orientation, or a variable form with a constant orientation. There were four familiarization trials each presented for 20-seconds. Following habituation infants were shown a violation trial which depicted objects that changed from the familiarization object in either form or orientation. The results suggest that when orientation and form where held constant infants dishabituated to the object that changed in form. When the objects' form was held constant and orientation varied, infants dishabituated to the stimulus that had a change in form. Lastly, when form varied and orientation was held constant, infants dishabituated to the object that changed in orientation. This research suggested that infants are able to discriminate objects that change in both form and orientation as young as 6-months of age. Subsequent research on object discrimination has used variants of this familiarization and violation procedure.

Three years later Cornell (1975) modified the procedure to test 4- to 5-month old infants' discrimination of pattern and orientation of patterns. Cornell presented a pair of identical images for 1-minute to familiarize infants, followed by a two test trials where one of the objects changed. The location of the change stimulus differed across test trials to prevent any form of side bias. The change stimulus changed in either pattern, orientation, or both pattern and orientation. The Cornell found that infants preferred to look at the stimulus that changed either in orientation or pattern over the previously familiarized stimulus suggesting that young infants can perceive changes in orientation and pattern in a visual paired comparison paradigm.

In 1979, four years later, Schwartz and Day further expanded the habituation familiarization and novel test trials to investigate orientation and shape perception in 2- to 3-month-olds. Infants were habituated to a single object over the course of 8 familiarization trials that lasted 20-seconds each. Following habituation, infants were given a short intertrial interval of 5 seconds, which was immediately followed by four 20-second test trials each separated by 5 seconds each. Then four test trials first presented the habituated stimulus, followed by two trials with a novel stimulus that varied on either shape or orientation, and then a novel object that varied on both orientation and shape. The stimuli consisted of simple geometric shapes of line and dot drawings. The results revealed that infants dishabituated more to the objects that changed in shape than orientations, but also that infants dishabituated to the orientation change compared to the habituated objects. These findings suggest that although infants can perceive and discriminate a change in orientation, they are quicker to notice the shape change.

The reviewed studies show that infants under 12 months are able to discriminate changes in shape and orientation objects through different habituation methods and stimuli types. Early discrimination research into the colour dimension similarly used a variant of the habituation procedure. In 1986, Bornstein and colleagues tested 3- to 4-month-old infants' colour vision and hue discrimination. Infants were habituated to a hue over the course of 15 15-second trials. Following habituation, a 7.5-second intertrial interval proceeded test trials. Test trials consisted of 9 15-second trials where infants were shown three trials of the habituated colour hue, three trials of a colour hue change consistent with adult colour boundaries (blue, red, yellow), and three trials with in-between colour boundaries (blue-green, green-yellow, yellow-red). Infants were additionally tested on one wavelength, two wavelengths within the same hue category, and two wavelengths from different hue categories. The results show that infants dishabituated on adult colour boundaries and had a fast rate of dishabituation for single or two wavelengths within the same category, suggesting that young infants are able to discriminate colours and do so according to adult perceived boundaries.

These early lines of research suggest that young infants are able to discriminate shape, orientation and colour changes to simple objects at fairly young ages. Even though more recent work has examined infant discrimination of colour (Pilling et al., 2003; Zemach et al., 2007; Skelton et al. 2017), orientation(Moore & Johnson, 2008), and shape changes (Mareschal et al., 2003), the majority of these studies still use and rely largely on the procedures and stimuli designed in the reviewed work, such as habituation and paired visual comparison with the use of similar stimuli. Although the discrimination literature uses similar tasks to test discrimination, the studies differs greatly on trial length ranges from 15 seconds to 60 seconds. The differing lengths of the trial times presents the issue as to what is the best timing for a discrimination procedure. Having short trial lengths may not provide infants with enough time to encode the stimuli and having longer trial lengths may make it difficult to remember stimuli presented on previous trials. Research has found that effective comparison and categorization of items requires visual short-term memory as sensory memory is stored within short-term memory, and visual short-term memory is therefore needed for the online processing of visual information (Ross-Sheehy, Oakes, & Luck, 2003). Therefore, any trial more than 30 seconds would exceed the limits of short-term memory and would tax children’s ability to discriminate between the stimuli and across trials. In addition to the timing issue, these experiments often used simple geometric shapes or line drawings, that primarily focus on a specific dimension. We need a task that would enable us to test multiple object features and more complex objects.

The ultimate goal of this new discrimination task is to determine whether infants in the age-range tested in Experiments 1 and 2 can discriminate the beasties. However, rather than simply examining the discrimination of the six beasties used in Experiments 1 and 2, we decided to look at discrimination along each of the three dimensions at multiple levels of degree of change to get a more complete picture of infant's perceptual abilities. We were also interested in whether this discrimination ability changes over development and whether it varies by the stimuli properties., i.e., are older children better at discriminating smaller changes in the beastie objects or different dimensions. Thus, we test participants' ability to detect changes in the colour, shape, and orientation of the beasties at varying degrees. We will sample beasties every 15 degrees from a continuous property wheel up to 60 degrees in for colour and shape and every 9 degrees for orientation order to make inferences about the cross situational word learning stimuli. This will then tell us whether our beastie stimuli are too similar and cannot be discriminated at the current metrics and possibly the cause for our overall lower looking times and non-replication. With this set of experiments, we should be able to identify what properties and what degree separation children need to see beasties as distinct objects.

Discrimination task

We wanted to design a discrimination task that would engage sensory or short-term memory, be able to test multiple properties, and more complex objects and enable examination of how the discrimination ability changes over development. Such a task would require a short trial length. Eschman and Ross-Sheehy (2019) recently designed such a task to test visual working memory. Their task was designed to overcome the methodological issues present in prior object discrimination work, specifically studies using long trial lengths which would exceed the limits of short-term memory. The task is composed of five parts; 1) a perceptual mask or attention getter, 2) a 1 second memory array, 3) 500 ms retention interval, 4) a 3 second test array, and 5) a reward movie presented on the side of the changed stimulus. This task still uses several of the measures used in object discrimination literature but was developed to engage visual perception and short-term memory. The task uses a visual paired comparison procedure where stimuli tested are presented on the right and left of the screen for the infant to compare. The memory array serves as a familiarization trial presenting the stimuli prior to a change. The retention interval engages memory and consolidation. The test array serves as the test trial engaging novelty where one of the two stimuli has changed, and the reward reinforces looking to the change side. Using this new paradigm, we should be able to test if children are able to detect the change in the beastie stimuli by their looking to the change side on the test array.

Since this is a relatively new task being applied to test object discrimination as opposed to working memory, we decided to first test adults. This serves three purposes. First, to check the validity of the testing measure on discrimination of the beastie stimuli. Second, adults could help us to see if the degree changes are discriminable or if there is a particularly harder or easier dimension to discriminate. Lastly, adults will provide us with initial information as to whether the beasties can be discriminated; if adults cannot tell the beasties apart, arguably infants will not be able to either.

3.2 Experiment 3a: Adult Discrimination

3.2.1 Methods

3.2.1.1 Participants

Forty- three participants (20 males; 18-33 years) were recruited from the University of East Anglia departmental subject pool. All participants had normal or corrected to normal hearing and vision, and none reported colour blindness. Informed consent was obtained in accordance with university and APA ethical standards. Participants received £8 for their participation.

3.2.1.2 Stimuli

A Dell computer running Experiment Builder (SR- Research, Ontario, Canada) presented the experiment on a 42-inch monitor at a distance of 100 centimetres. An EyeLink 1000 plus remote tracker was used. The eye tracking camera was located at the base of the monitor on a small stand at a distance between 600 to 700 centimetres. The eye tracker was set for monocular, focused on the right eye and tracked gaze position using pupil and corneal reflections of an infrared light source. Eye position was maintained using a target sticker, allowing the eye tracker to relocate the eye as the participant moved or blinked. The tracker's sampling rate was 500 Hz. There were two additional cameras, one located at the bottom of the monitor to record the participant's face, and one located at the back of the room to record the experiment as it was presented on the monitor.

The stimuli consisted of 44 novel objects called "beasties." The beasties were constructed in Matlab and Microsoft PowerPoint to have well-controlled metric properties. The body shapes were defined by radial frequency components (Zahn & Roskies, 1972) that provide an evenly parameterized similarity space without category boundaries that is well localized neutrally. A second dimension was added via equidistant colours sampled from a 360 degree continuous colour space (CIE Lab, 1976), and a third by rotating each shape around its major axes of elongation. Because these stimuli are also used with children, eyes and legs were added for interest. The set of beasties used for Experiment 3a and 3b can be found in the Appendix.

Three sets of beastie stimuli were created to examine discrimination of shape, colour and orientation differences. Stimuli within each set differed only on the examined dimension and were all the same on the other two dimensions. Within each set, adjacent stimuli differed by 15 degrees resulting in 18 shape and 18 colour stimuli. The orientation set contained only 8 stimuli, however, because the shapes were symmetrical and thus orientations beyond 90 degrees become mirror images and differed by 9 degrees. Beasties ranged from 12 to 18 cm in height and width and had a visual angle between 6 and 10 degrees.

Each trial consisted of a sequence of two arrays. Each array contained two beasties; one presented 25 cm to the right of midline, the other 25 cm to the left**.** The experiment computer sent messages specifying trial information (e.g., start and end of a trial, stimulus information) to the eye tracking computer which recorded these along with the gaze position data. These codes allowed for the integration of participants' gaze data with the stimulus information for later analysis.

3.2.1.3 Procedure

Participants were tested in a small experimental room. Adult participants were tested using the same procedure as child participants and thus the experiment began with a short video of *Elmo's World.* During this video, the experimenter placed the tracking sticker on the participants' forehead. To calibrate the eye tracker, participants were shown a looming black and white geometric object at five points of the screen (middle, top, bottom, right, left). The experimenter viewed an image of the gaze position relative to the target and indicated when the participant was looking at the target. This procedure mapped raw eye position data to the camera image data and thereby mapped gaze position to the stimulus presentation.

The experiment comprised 72 trials separated into 6 blocks of 12 trials. Each block included a trial at each of the four discrimination steps (shape and colour: 15, 30, 45, 60 degrees; orientation: 9,18, 27, 36 degrees) for each of the three dimensions (colour, shape, and orientation). Each trial was composed of five parts: 1) a gaze-contingent attention grabber, 2) a memory array, 3) a retention interval, 4) a test array, and 5) a movie reward (Figure 12). All five parts were presented on a dark grey background. The attention grabber was a gaze contingent looming rainbow star and the movie reward was a novel dancing animal. Once participants looked to the star it disappeared, and the memory array appeared. This array contained two identical beasties, one on the right and another on the left of midline. The memory array was followed by a retention interval with a blank grey screen. This was followed by the test array in which one of the two beasties had changed. The test array remained for 3000 ms, after which a 7000 ms reward video of a dancing animal played on the side of the changed beastie. The order of dimensions and step sizes, as well as the particular stimulus used in the memory array, were all randomized and counterbalanced for each participant. Each stimulus occurred in the memory array exactly once across the experiment. Adults did 72 trials with one of the two retention intervals (250 or 500 ms), before doing an additional 72 trials with the other retention interval. Which retention interval subjects saw first was randomly determined and the 72 trials were counterbalanced for target side.

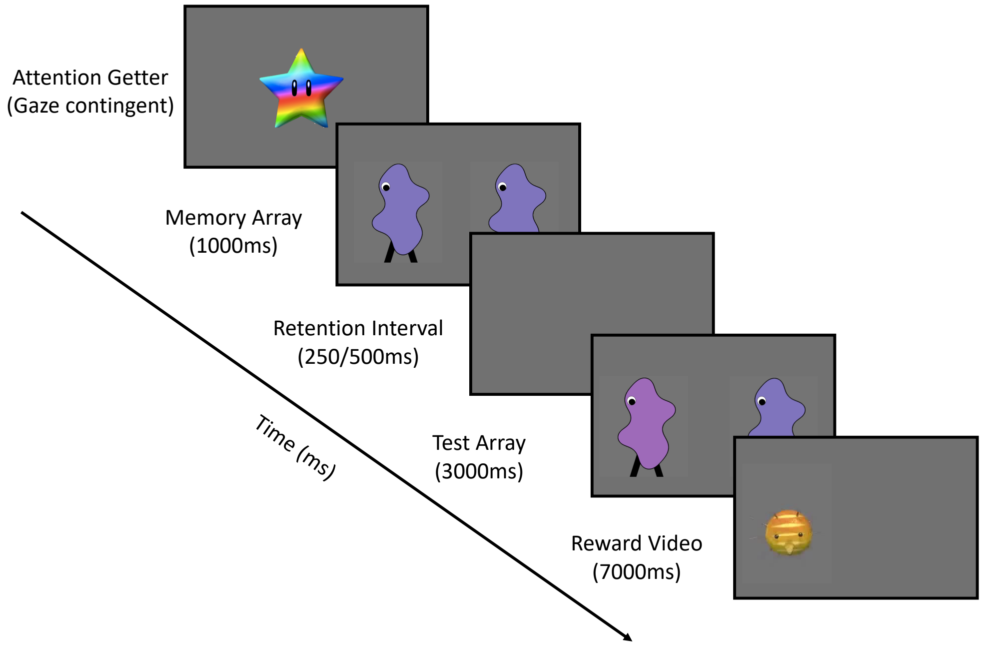

Figure 12. Sequence of events in each trial.

3.2.1.4 Data Analysis

Raw eye position data was organized into fixations, saccades, and blinks using Data Viewer (SR- Research, Ontario, Canada). For analysis, raw eye data was further extrapolated to create Areas of Interest (AOI). A separate AOI, each 400 by 400 pixels, surrounded each beastie. The AOIs were 50% bigger than the stimuli to allow for calibration error and drift in the eye tracker. Interest area reports for the memory and test arrays provided looking time and number of fixations for each AOI, switches between

AOIs and average pupil dilation. Each trial was broken into five individual segments that defined the key events. Our metric for discrimination was greater looking to the change side on the 3-second test array. Therefore, we created a variable called side which coded whether a look was to the changed side or the no change side of the array.

Our main questions were: 1) at what degree of difference were adults able to discriminate stimuli from each dimension, 2) did this differ by dimension, and 3) did retention interval length influence discrimination ability. To answer these questions, we ran a series of mixed-effects models using the lmer function in the linear mixed-effects package lme4 (Bates, Maechler, Bolker, & Walker, 2015) in R (R Core Team, 2016). Using mixed models allows us to estimate simultaneously, but separately, the main effects of different variables, as well as random effects. For example, we can estimate the main effect of dimension and step on looking time and any interactive effects between dimension and step, while controlling for random effects such as those related to subjects. Degrees of freedom and p values for all main effects and interactions were obtained from the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2013).

Our initial model predicted looking time, defined as the total amount of time spent looking within an AOI, during the test array as a function of our main variables of interest: side (change, no change), dimension (shape, colour, orientation), step size (shape and colour: 1- 15°, 2-30°, 3-45°,4- 60° & orientation: 1- 9°, 2-18°, 3-27°,4- 36°), and retention interval (250 ms v. 500 ms). We also examined effects of trial number, block, change side (left v. right), memory stimulus, change stimulus (which particular stimulus object changed), and gender. All hypothesized predictor variables were added into the model which was then simplified using log-likelihood tests. All continuous predictors were centred, and dimension, step, and change look were effect coded. Visual inspection of the data suggested that discrimination was influenced by step size, getting better with increasing steps, and dimension, such that colour and orientation were similar, but both differed from shape. Thus, dimension was coded to compare colour and orientation to shape, step was coded to compare subsequent steps to each other (e.g., step 1 to 2, 2 to 3, and step 3 to 4), and side was coded to compare change to no change. A preliminary analysis revealed no effect or interactions of trial number, block, side of change (left v. right), memory stimulus, or change stimulus. This analysis also revealed a significant effect of gender. Follow-up analyses with this factor included revealed that females looked longer to changes for the colour set in particular. However, because the overall pattern of findings with respect to the main variables of interest did not differ for females and males, and because it is not clear that the gender difference has implications for our main questions of interest, we report data from analyses without this factor. The results from the analyses including gender are included in the Appendix.

Follow-up analyses examined performance for each of the three dimensions individually. In addition, to examine the relation between patterns of looking during encoding and discrimination, we ran a second set of analyses investigating whether looking to both objects or sampling both objects on the memory and test array led to better discrimination, along with examining the location of participant looking.

3.2.2 Results

To examine our main questions, what degree of difference is needed for adult discrimination of shape, colour and orientation changes, and is this different across dimensions and/or retention intervals, we included a full factorial combination of dimension, step, side, and retention interval predicting looking time during the test array. Data exploration and log likelihood tests indicated that the best fitting random effects structure contained random intercepts for subject. The fixed effects justified by the data included a three-way interaction of side, dimension, and step. Retention interval was not found to be a contributing factor and was removed from the model. The results can be found in Table 1.

Table 1 Main model t statistics

Effects	Variables	t- statistic
Main Effect	Side: Change	t (1927.99)=50.40***
Two-Way	Side by Dimension	
	Change: Colour by Shape	t (1927.57)=10.72***
	Change: Orientation by Shape	t (1927.18)=10.22***
	Side by Step	
	Change: 1 by 2	t (1927.38)=-12.49***
	Change: 2 by 3	t (1927.60)=-13.03***
	Change: 3 by 4	t (1927.47)=-9.35***
Three-Way	Side by Dimension by Step	t (1927.10)=-2.85**

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

These results show that adults were able to discriminate the beasties across all three dimensions on the first step, 15 degrees for shape and colour and 9 degrees for orientation, and discrimination improved as step increased. The results also show that although adults could detect the change side in all dimensions, adults looked significantly more to the change side in colour and orientation compared to shape. Although the comparison between the dimensions is informative, we are not necessarily interested in testing if a certain degree change is the same across dimensions, instead we are interested in whether children can tell the difference when degree changes occur within a dimension, thus, we looked at the data for each dimension separately.

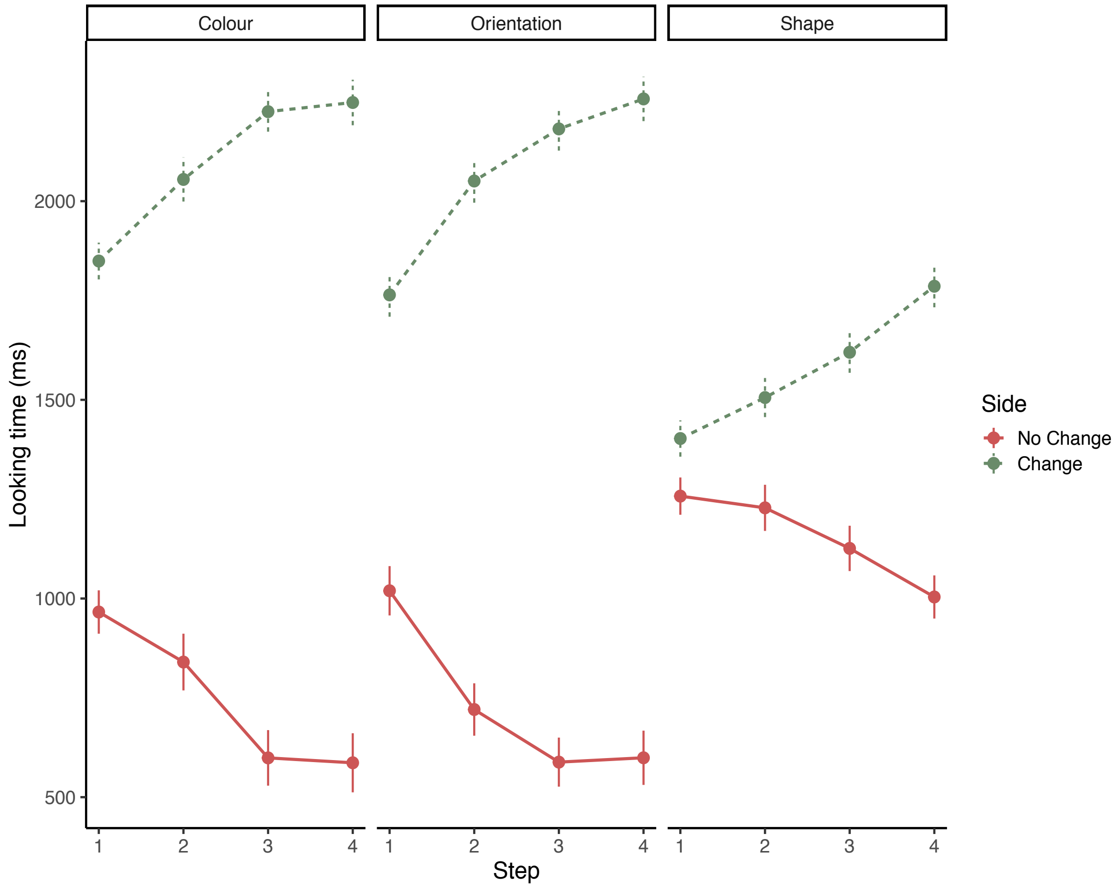

Figure 13. Looking to the change and no change side by dimension and step size in adult participants.

Analysis of individual dimensions

For the colour dimension, likelihood ratio tests indicated that the best fitting random effects structure contained random intercepts for subject and the fixed effects justified by the data included a two-way interaction of side and step. There was a reliable main effect of change look, such that participants looked longer to the side (change side), $t(582.99)=34.56$, $p<0.001$. There was a reliable two-way interaction for side by step, whereby participants looked significantly less to the change side for step 1 compared to step 2 $t(580.35)=-6.89$, $p<0.001$, step 2 compared to step 3 $t(580.87)=-7.58$, $p<0.001$, and step 3 compared to step 4, $t(581.02)=-4.55$, $p<0.001$.

For the orientation dimension, likelihood ratio tests indicate that the best fitting random effects structure contained random intercepts for subject. The fixed effects justified by the data included a two interaction of side and step. There was a reliable main effect of change side, such that participants looked significantly longer to the change side, $t(585.43)= 33.71$, $p<0.001$. There was also a reliable two-way interaction for side by step whereby participants looked significantly less to the change side for steps 1 compared to step 2 $t(584.46)=-8.61$, $p<0.001$, step 2 compared to step 3 $t(585.49)=-7.41$,$p<0.001$, and step 3 compared to step 4 $t(585.45)=-4.77$, $p<0.001$.

For the shape dimension, the likelihood ratio tests indicated that the best fitting random effects structure contained random intercepts for subject and the fixed effects justified by the data included a two-way interaction of side and step. There was a reliable main effect of side, such that participants looked significantly longer to the change side, $t(595.00)=13.65$, $p<0.001$. There was a reliable two-way interaction of side by step such that participants looked less to the change side for step 1 compared to step 2, $t(595.00)=-5.19$, $p<0.001$, step 2 compared to step 3, $t(595.00)=-6.86$, $p<0.001$, and step 3 compared to step 4, $t(595.00)=-6.64$, $p<0.001$.

The individual dimension models were all consistent with the overall model in showing that participants were able to discriminate the smallest changes tested and that looking to the changed stimulus increased with larger step changes. Overall these results suggest that the answer to main questions are 1) adults can discriminate the smallest change tested on all three dimensions, 2) changes in shape appear to be harder to discriminate than changes in colour or orientation, and 3) the retention interval did not influence discrimination. These results, though informative, do not tell us what information in the visual arrays adults use to discriminate the objects. To examine this issue, we looked at the patterns of visual exploration during the memory array and test array.

Visual exploration

Visual exploration was characterized in terms of a number of variables, specifically whether adults sampled images on both the memory and test array, as well as looking in different areas of interest (AOI). Sampling coded dichotomously whether participants looked at both the right and left sides of the memory array. We believe that sampling of the images on either array might help the participant gather featural information about the beasties and then use that information to discriminate at test. To examine what parts of the stimuli might best inform discrimination, we created two new interest areas to examine looks to the top and bottom diagonal halves of the beasties. This was based on our intuition that the addition of the legs to the stimuli meant that the bottom region around the legs might be particularly useful in identifying changes in the shape and orientation of the stimuli as a reference point. Having two areas thus provides a means of examining how looks to the bottom, compared to other parts of the stimuli, support discrimination and whether this is different across the three dimensions.

Our main questions for our analysis of visual exploration were 1) does looking to both images on the memory array, sampling, lead to differences in looking to the change v. no change side of the test array, 2) does sampling the test array lead to differences in looking to the change v. no change side of the test array 3) does looking to the top or bottom half of the beastie relate to differences in test array looking. Sampling was effect coded to compare participants who did not look to both sides on the memory array to those who did.

Sampling Images during Memory Array

Table 2 Sampling memory array model t statistics

Effects	Variables	t- statistic
Main Effect	Sampling: unsampled	t (2877.39)=-3.63***
Two-Way	Sampling by Side: Sampled | Change side	t(2801.58)=6.15***
Three-Way	Sampling by Side by Step	
	1 by 2	t (2799.81)=-3.63***
	2 by 3	t (2800.53)=-4.08***
	3 by 4	t (2801.05)=-3.99***
Four-Way	Sampling by Side by Step by Dimension	t(2799.39)=-1.99*

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

To examine the relationship between sampling and discrimination, we created a model that predicted looking on the test array from side, sampling on the memory array, dimension and step. Log likelihood tests indicated that the best fitting random effects structure contained random intercepts for subject and the fixed effects justified by the data included a four-way interaction of side, sampling, dimension, and step. The full results of the memory array sampling model can be found in Table 2. These results show that although there is more looking on unsampled trials, sampling is related to significantly more looking to the change at test. There was a significant three-way interaction whereby trials that were sampled had more looking to the change side across step. Lastly, there was a significant four-way interaction between sampling, side, step, and dimension. To investigate the four-way interaction, we examined the colour, shape, and orientation dimensions separately. For the colour, shape, and orientation dimensions, log likelihood tests indicated the best fitting model contained a random effect of subject and fixed effects for side, step, and sampling.

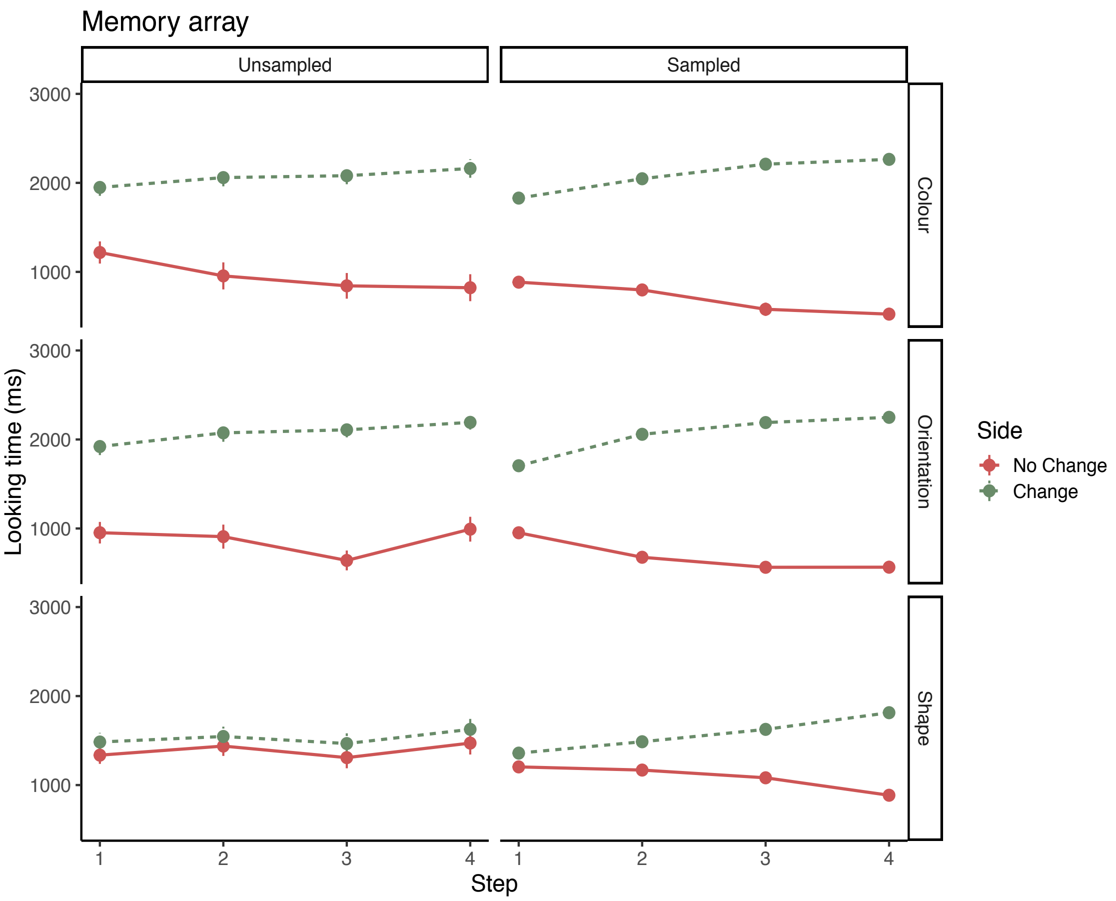

Figure 14. Looking time to the change and no change side on the memory array for sampled and unsampled trials, across the three dimensions.

For the shape dimension, there was a significant main effect of side, such that participants had significantly more looking to the change side, $t(901.99)=8.66$, $p<0.001$. There was also a significant main effect of sampling, such that participants looked more on unsampled trials, $t(967.41)=-2.44$, $p<0.05$. There was a significant two-way interaction between side and sampling, such that participants looked more to the change side if they had sampled on the memory array, $t(902.44)=4.79$, $p<0.001$. Lastly, there was a significant three-way interaction between side, sampling, and step, with a significant increase in looking to the change side for sampled trials from step 1 to 2, $t(901.27)=2.71$, $p<0.01$, step 2 to 3, $t(901.82)=3.41$, $p<0.001$, and step 3 to 4, $t(902.99)=3.46$, $p<0.001$. There was no significant difference between looking to the change side for unsampled trials, $t(275.62)=1.80$, $p=0.74$. These results suggest that although participants spent more time looking on unsampled trials, sampling of the memory array was significantly related to participants' ability to discriminate the shape changes. In addition, this effect was also seen across step sizes, indicating that sampling aided in perception of smaller degree changes in the shape of the beasties.

For the colour dimension, there was a significant main effect of side, with was significantly more looking to the change side, $t(879.34)=30.71$, $p<0.001$. There was also a significant main effect of sampling, whereby participants had significantly more looking on unsampled trials, $t(942.72)=-2.43$, $p<0.05$. Lastly, there was a significant two-way interaction, such that participants looked more to the change side when they had sampled both sides of the memory array, $t(876.62)=3.60$, $p<0.001$. There was no effect of step. Similar to the shape dimension model, the colour model results suggest that sampling of the memory array significantly increased participants' looking to the change side despite participants looking more on unsampled trials. However, there was no interaction with step suggesting that sampling of the memory array did not additionally help participants to see smaller changes in colour.

For the orientation dimension, there was a significant main effect of side, such that participants had more looking to the change side, $t(883.14)=33.25$, $p<0.001$. There was also a significant main effect of sampling, whereby participants looked significantly more on unsampled trials, $t(952.14)=-2.42$, $p<0.05$. There was a significant two-way interaction, such that participants looked significantly more to the change side for sampled trials, $t(880.18)=2.30$, $p<0.05$. Lastly, there was a significant three-way interaction between sampling, side, and step, whereby participants had significantly more looking to the change side on sampled trials from step 1 to 2, $t(876.44)=-3.06$, $p<0.01$, step 2 to step 3, $t(876.72)=-2.35$, $p<0.05$, and step 3 to step 4, $t(878.28)=-2.60$, $p<0.01$. The orientation model echoed similar findings from the shape and colour sampling models, in that participants' discrimination was improved on trials in which they sampled the memory array despite looking more on unsampled trials. In addition, on sampled trials there was an increase in looking to the change as step increased, suggesting that sampling helped participant see smaller changes in the stimuli.

Overall, these results demonstrate that sampling both images on the memory array resulted in greater discrimination of the test array. Participants who sampled both images showed increases in looking to the changed side as step increased, but the largest difference was seen for the shape dimension. Given that the shape changes of these stimuli appear harder to discriminate compared to the colour and orientation changes, these results suggest that sampling both memory images is a critical predictor of discrimination. These results are particularly interesting because the images on the memory array are identical and there was significantly less looking on trials that were sampled compare to unsampled trials. Therefore, it may not be that sampling the memory array in and of itself aides in discrimination, but the process and pattern of looking that matters. Specifically, sampling the images requires participants to look to both of the images or both sides of the screen. Developing this type of looking to one object and then the other on the memory array may encourage participants to continue this pattern on the test array. However, this theory rests upon whether sampling on the test array also increases participants' looking to the change side and discrimination of the objects. If sampling images on the test array significantly improves discrimination, then it can be argued that sampling on the memory helped to develop this pattern of looking back and forth. However, if not sampling images on the memory array leads to more looking to the change side then it could be that sampling of the memory array provided a strong memory of the images allowing the participants to quickly detect the change and caused no need to sample the images. Therefore, we next looked at sampling on the test array in relation to discrimination ability.

Sampling Images during Test Array

Since there was a relationship found between sampling the images on the memory array, we sought to see if there would be a relationship between sampling on test and looking to the change side. Log likelihood tests indicated that the best fitting random effects structure contained random intercepts for subject and the fixed effects justified by the data included a four-way interaction of side, sampling, dimension, and step. The full results of the sampling model can be found in Table 3. The results suggest that although trials that were unsampled had more overall looking, trials that were sampled had more looking to the change side. The results also suggested that there was more looking for trials that were sampled for shape as opposed to colour. There was a significant three-way interaction whereby trials that were sampled had more looking to the change side across step. Lastly, there was a significant four-way interaction between sampling, side, and step. To investigate the four-way interaction, we examined the colour, shape, and orientation dimension separately. For the shape, colour, and orientation dimensions, loglikelihood tests indicated the best fitting model contained a random effect of subject and fixed effects for side, step, and sampling.

Table 3 Sampling test array model t statistics

Effects	Variables	t- statistic
Main Effect	Sampling: Not sampled	t (2543.16)=-30.72***
Two-Way	Sampling by Side: Sampled | Change side	t(2522.81)=12.91***
	Sampling by Dimension: Sampled | Colour by shape	t(2496.03)=-2.47*
Three-Way	Sampling by Side by Step	
	1 by 2	t (2497.74)=-3.43***
	2 by 3	t (2493.90)=-4.42***
	3 by 4	t (2490.74)=-2.79***
	Sampling by Side by Dimension	
	Colour by Shape	t (2492.99)=3.97***
	Orientation by Shape	t (2489.31)=2.99**
Four-Way	Sampling by Side by Step by Dimension	t(2492.18)=-2.37*

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

For the shape dimension, there was a significant main effect of side, such that participants had significantly more looking to the change side, $t(786.78)=7.83$, $p<0.001$. There was also a significant main effect of sampling, such that participants looked significantly more on unsampled trials, $t(807.70)=-16.86$, $p<0.001$. There was a significant two-way interaction between side and sampling, whereby participants had more looking to the change side for sampled trials, $t(902.44)=4.79$, $p<0.001$. There was a significant two-way interaction between sampling and side, where participants had more looking to the change side for test trials that were sampled, $t(769.08)=2.05$, $p<0.05$. Lastly, there was a significant three-way interaction between side, sampling, and step, such that participants had a significant increase in looking to change for sampled trials from step 2 to 3, $t(762.91)=-2.24$, $p<0.05$, and step 3 to 4, $t(763.35)=-2.27$, $p<0.05$. These results revealed that participants had overall more looking on trials that they did not sample the images, but they had more looking to the change side on sampled trials suggesting that sampling the images on the test array significantly increase participants' ability to discriminate the object on the shape dimension. Sampling also increased looking to the change side as step increased suggesting sampling aides in the discrimination of changes in degree within the shape dimension.

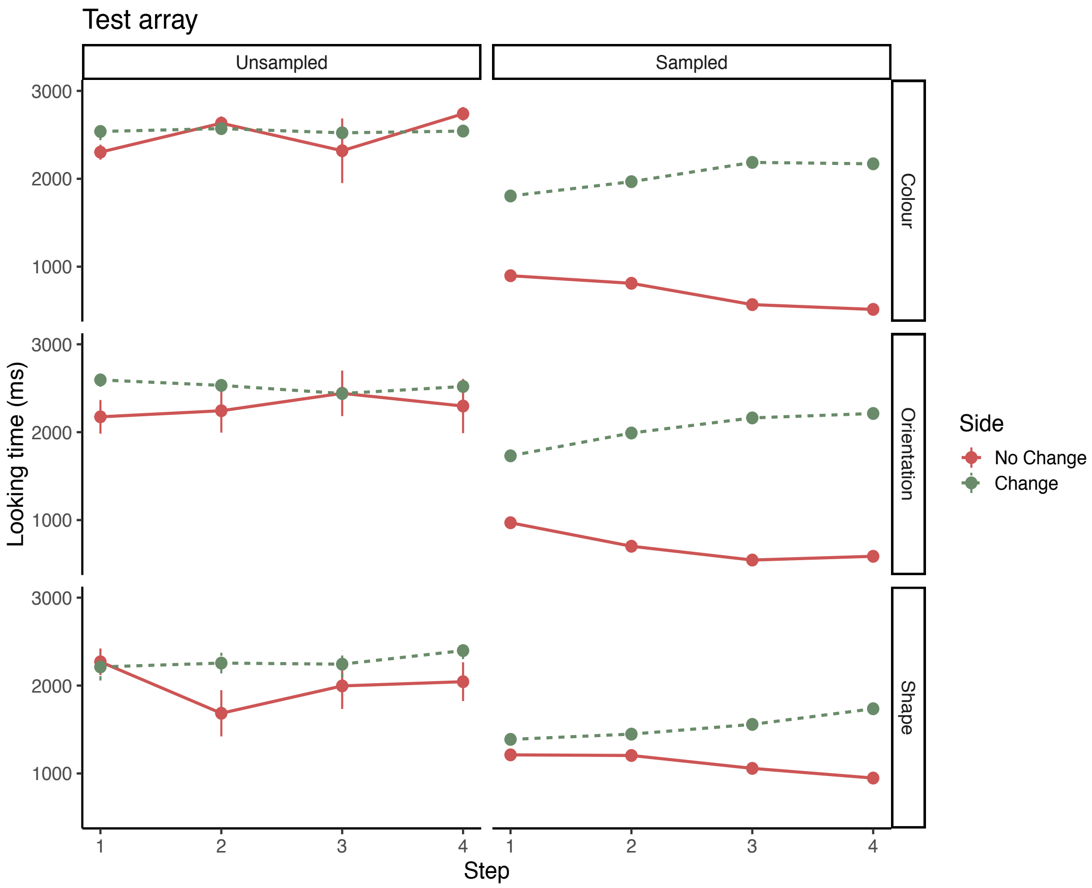

Figure 15. Looking time to the change and no change side on the test array for sampled and unsampled trials, across the three dimensions

For the colour dimension, there was a significant main effect of side, such that participants had significantly more looking to the change side, $t(852.75)=14.12$, $p<0.001$. There was a significant main effect of sampling of the test array, such that participants had significantly more looking on unsampled test trials, $t(862.91)=-19.01$, $p<0.001$. There was a significant two-way interaction between side and sampling of the test array such that participants had more looking to the change side on test trials that were sampled, $t(854.66)=10.40$, $p<0.001$. Lastly, there was a significant three-way interaction between side, sampling, and step, such that participants had a significant increase in looking to change for sampled trials from step 1 to 2, $t(833.85)=-2.61$, $p<0.01$, step 2 to 3, $t(816.27)=-2.35$, $p<0.05$, and step 3 to 4, $t(811.39)=-2.26$, $p<0.05$. These results suggest that sampling the test array aides in discrimination of the colour dimension and at all of the degree steps within the colour dimension.

For the orientation dimension, there was a significant main effect of side, such that participants had significantly more looking to the change side, $t(846.59)=16.31$, $p<0.001$. There was a significant main effect of sampling of the test array, such that participants had significantly more looking on unsampled test trials, *t*(857.91)=-18.73, $p<0.001$. There was a significant two-way interaction between side and sampling of the test array, such that participants had more looking to the change side on test trials that were sampled, *t*(847.05)=9.88, $p<0.001$. Lastly, there was a significant three-way interaction between side, sampling, and step, such that participants had a significant increase in looking to change for sampled trials from step 1 to 2, *t*(822.01)=-3.79, $p<0.001$ and step 2 to 3, *t*(815.05)=-3.62, $p<0.001$. The orientation test array sampling model results suggest that sampling the images on the test array aided participants ability to discriminate the orientation dimension and changes in degree within the dimension. However, there was no difference in looking on the sampled of unsampled trials for the 45-and 60-degree changes, suggesting sampling only helps discrimination of the orientation smaller changes in stimuli.

The results from the sampling of the memory and test array show that trials on which participants looked to both sides of the array resulted in more looking to the change side, i.e. they were better able to discriminate the change in the beastie. It is important to note that participants were not told that the images on the memory were identical and the images on the test array were different, nor that this was a change detection task. Participants looking back and forth on the memory array may be an indicator that when two objects are present, they will likely look back and forth regardless if it is the memory array or test array. The percentage of trials on which sampling occurred on both the memory and test array was 74% of trials for all participants and was fairly even across dimension (colour: 72%, orientation: 73%, and shape: 77%), suggesting that participants were more likely to sample the test array if they had sampled the memory array. These findings show that participants do sample on the majority of trials and do so fairly evenly across dimension. The sampling behaviour found on the memory may be a simple pattern of behaviour that they carry throughout the trials. However, it is the sampling on the test array which may make it easier to detect the differences, leading to quicker and longer looking to the change side. These analyses of sampling show that the way in which participants distributed their looks, can lead to better discrimination. Next, we investigated whether location of looking to the stimuli affected discrimination.

Top and Bottom Area of Interest Looking

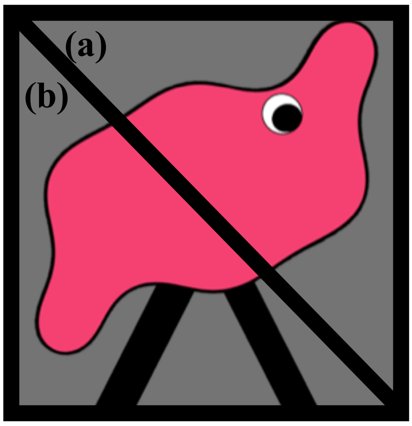

Figure 16. Area of interest (AOI) draw around an orientation dimension. (a) top half of interest area, (b) bottom half of interest area.

To answer our third question about how visual exploration relates to discrimination: does looking to the top or bottom half of the beastie relate to differences in test array looking, we created two new areas of interest (AOI). These new AOIs divided the beasties into a top half that included the eyes and the bottom half that included the legs (see Figure 16). We examined visual exploration with a model that included side, dimension, step, and AOI (top v bottom). Log likelihood tests indicated that the best fitting random effects structure contained random intercepts for subject and the fixed effects justified by the data included a four-way interaction of side, dimension, step, and AOI.

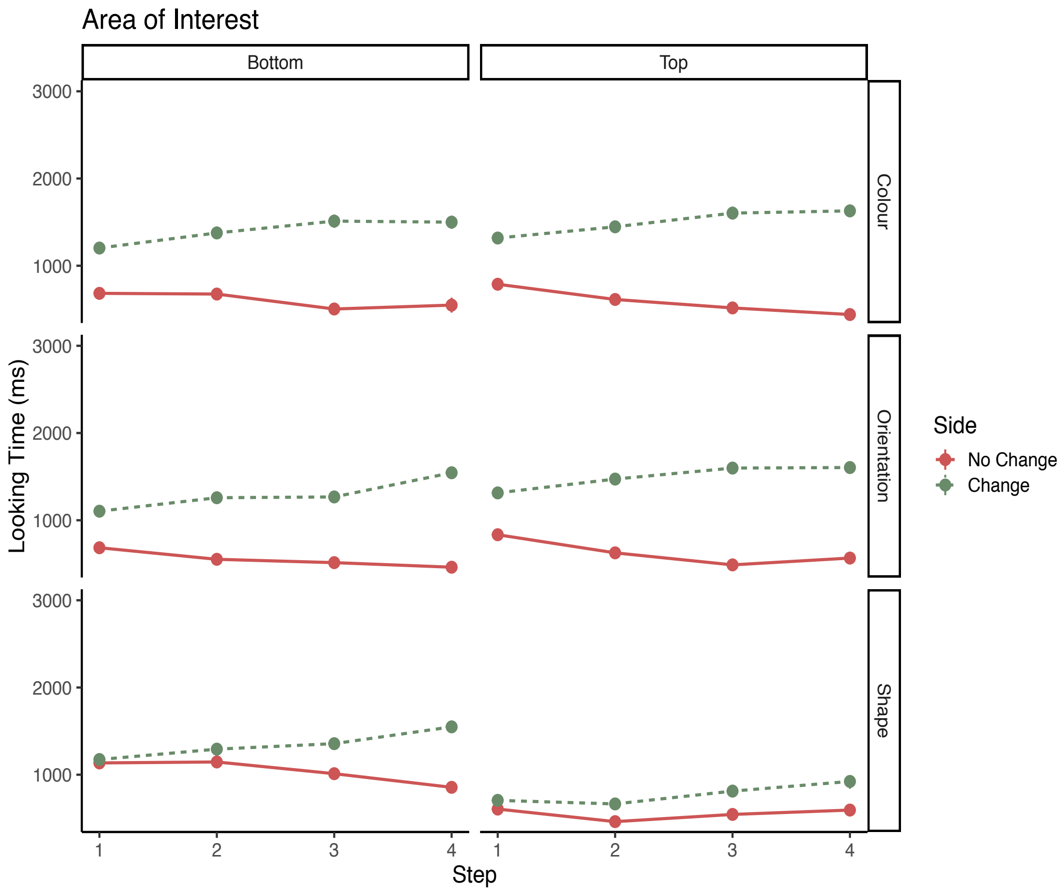

Figure 17. Looking time to the change and no change side on all three dimensions for the interest areas bottom and top

There was a main effect of AOI, were there was more looking in the bottom AOI, $t(3572.71)=5.21$, $p<0.001$. There was a significant two-way interaction between dimension and area of interest were there was less looking to the top AOI for shape compared to colour, $t(3559.27)=-6.33$, $p<0.001$ and shape compared to orientation, $t(3559.04)=-9.97$, $p<0.001$. Lastly, there was a significant four-way interaction between side, dimension, step, and AOI, $t(3558.60)=2.92$, $p<0.01$. The four-way interaction indicated there was a significant difference between the colour and the shape dimension. Visual examination of the data suggests the shape dimension was driving the interaction; thus, we investigated the shape dimension separately.

The shape model included side, step, and AOI (top and bottom). Log likelihood tests indicated that the best fitting random effects structure contained random intercepts for subject and the fixed effects justified by the data included a three-way interaction of side, step, and AOI. There was a main effect of side, with significantly more looking to the change side, $t(1095.06)=9.11$, $p<0.001$. There was a main effect of AOI, with more looking to the bottom AOI, $t(1126.98)=17.11$, $p<0.001$. There was a two-way interaction of side and AOI, with significantly less looking to change for the top AOI, $t(902.44)=-4.79$, $p<0.001$. Additionally, there was a significant three-way interaction between side, step and AOI, with a significant increase in looking from step 2 to step 3 for the change side, $t(1091.95)=-2.60$, $p<0.01$ and 3 to 4, $t(1094.46)=-3.03$, $p<0.01$ in the bottom AOI.

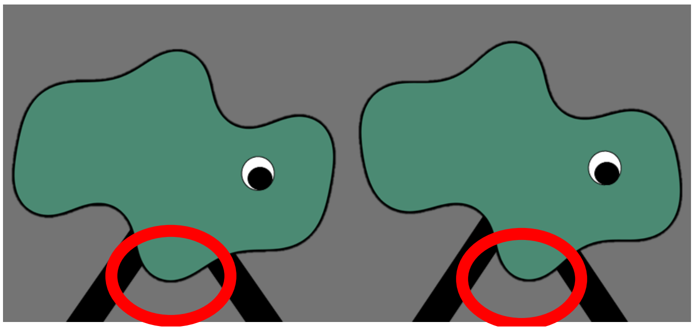

Figure 18. Shape beasties separated by 30-degrees (step2). Red circle indicates legs as points of reference to see shape change.

These results suggest that where participants look at the beastie may influence their discrimination ability, especially for the shape dimension. For shape trials, participants that looked to the bottom AOI had greater looking to the change side. It may be that this area contained more information as to the shape change by maximizing the degree of change for the shape properties of the beasties body, as it had the straight legs to compare against (see Figure 18). For the other dimensions, this may not have been a vital area to help with discrimination, as colour was distributed equally across the beastie so it did not matter participants looked at the top or the bottom and for the orientation dimension, the top area of interest may be as informative as the bottom half.

3.2.3 Discussion

We found that adults are able to discriminate even small changes in the colour, orientation, and shape of the beasties, although changes in shape were clearly not discriminated as well as changes in the other dimensions. In addition, participants looked more to the change side as step increased or as the objects became more dissimilar. Further, discrimination was predicted by sampling of both images on the memory array and looking to the bottom of the stimulus images. Specifically, sampling both images on the memory and test arrays was related to increases in looking to the change side. We believe sampling both memory array images helped participants to verify the differences when a beastie was changed on the test array of the objects leading to better change detection. Looking more to the bottom half of the beasties promoted change detection for the shape dimension, which was the most difficult overall. Overall, the adult data suggest the beasties objects are discriminable and this task is viable in assessing this discrimination. We also found that sampling of the objects on both the memory and test array and looking to the bottom AOI for the shape dimension further aides in discrimination.

3.3 Experiment 3b: Children

The adult discrimination data show that the beastie objects are discriminable based on their colour, orientation, and shape, and that detection of changes increases as the changes increase in step (degree of change increase). These results suggest that the beasties used in the cross situational word learning studies of Experiments 1 and 2 would be discriminable as the closest neighbours in shape and colour among those stimuli differed by 60 degrees, or 4 steps. However, we cannot conclusively say children in the cross situational word learning task were able to discriminate the beastie objects, as children and infants perceive the world and objects different to that of adults (Smith, 1989). Therefore, in order to rule out the beasties as a cause for the non-replication of cross situational word learning in Experiments 1 and 2 we test children in the object discrimination task.

3.3.1 Methods

3.3.1.1 Participants

One hundred and sixty infants (80 males) were recruited from a Southeast college town in England via community outreach and a participant registry. Eleven infants were excluded from the final sample due to fussiness (3) and technical/ experimenter error (8). Data from 9 additional infants were excluded from analyses for not completing at least 24 trials or two blocks of trials. The final sample consisted of 140 infants (71 males), in four age groups: 42 12-15-month-olds (21males), 32 17-20-month-olds (17males), 32 22-25-month-olds (14males), and 35 27-30-month-olds (19 males). All infants were from middle class working families that had normal or corrected to normal hearing and vision. None of the infants' parents reported a family history of colour blindness. Participants received a toy and a t-shirt for their participation.

3.3.1.2 Stimuli

The apparatus and stimuli were the same as Experiment 3a.

3.3.1.3 Procedure

The procedure was identical to Experiment 3a, with the exceptions that participants were seated on their caregiver's lap in front of the monitor and infants only saw one experimental set (72 trials) with the 500 ms retention interval. The trials separated into 6 blocks of 12 trials. Each block included a trial at each of the four discrimination steps (shape and colour: 1- 15°, 2-30°, 3-45°,4- 60° & orientation: 1- 9°, 2-18°, 3-27°,4- 36°) for each of the three dimensions (colour, shape, and orientation). Most infants did not get through all 72 trials. On average infants were able to get through of 56 trials (12-15mo: 55 trials, 17-20mo: 56 trials, 22-25mo: 59 trials, 27-30mo: 54 trials), with an average of 19 trials per dimension.

3.3.1.4 Data Analysis

Our two main questions remain the same; 1) at what degree of difference were infants able to discriminate stimuli from each dimension, 2) did this differ by dimension. To answer these questions, we ran a series of mixed-effects models using the lmer function in the linear mixed-effects package lme4 (Bates, Maechler, Bolker, & Walker, 2015) in R (R Core Team, 2016). In addition, we were also interested in whether discrimination ability differed across age, thus, age group was added to the analysis. Age groups, a categorical variable, was effect coded to compare 12- to 15-month-olds to 17- to 20-month-olds, 17- to 20-month-olds to 22-to 25-month-olds, and 22-to 25-month-olds to 27-to 30-month-olds.

Our initial model predicted looking time, defined as the total amount of time spent looking within an AOI, during the test array as a function of our main variables of interest: side (change, no change), dimension (shape, colour, orientation), step size (shape and colour: 1- 15°, 2-30°, 3-45°,4- 60° & orientation: 1- 9°, 2-18°, 3-27°,4- 36°), and age group (12-15mo, 17-20mo, 22-25mo, 27-30mo). All hypothesized predictor variables were added into the model which was then simplified using log likelihood tests. All continuous predictors were centred, and dimension, step, and side were effects coded. Visual inspection of the data suggested that discrimination was influenced by step size, getting better with increasing steps, and dimension, such that colour and orientation were similar, but both differed from shape. Thus, dimension was coded to compare colour and orientation to shape, step was coded to compare subsequent steps to each other (e.g., step

1 to 2, 2 to 3, and step 3 to 4), and side was coded to compare change to no change. A preliminary analysis revealed no effect or interactions of trial number, block, change side (left v. right), memory stimulus, change stimulus, or gender.

3.3.2 Results 1

Data exploration and log likelihood tests indicated that the best fitting random effects structure contained random intercepts for subjects and stimuli. The fixed effects justified by the data included a two-way interaction of side and dimension, $f(3187.20)=4.81$, $p=0.008$ and a three-way interaction of side, step and age group, $f(3186.90)=3.08$, $p=0.001$. There was a reliable main effect side, with more looking to the change side, $t(3187.08)=2.92$, $p<0.01$. There was a significant two-way interaction between side and dimension with more looking to the change side for the colour dimension compared to the shape dimension, $t(3186.90)=2.81$, $p<0.01$. There was a reliable two-way interaction between side and age group, with significantly more looking to the change side for the 22-25-month age group compared to the 27-30-month age group, $t(3187.29)=2.06$, $p<0.05$. Lastly, there was a significant three-way interaction between side, step, and age group, with significantly more looking to the change side for the 22-25-month age group compared to the 27- 30-month age group for step 4 compared to step 3, $t(3187.25)=-2.67$, $p<0.05$. Taken together these results suggest that children are able to discriminate the beasties overall. However, this discrimination varies between the dimensions and age groups. Step also appears to affect discrimination of the beasties as it relates to age groups. To in order to fully understand further investigate the effects of dimension and age group, we will examine these separately.

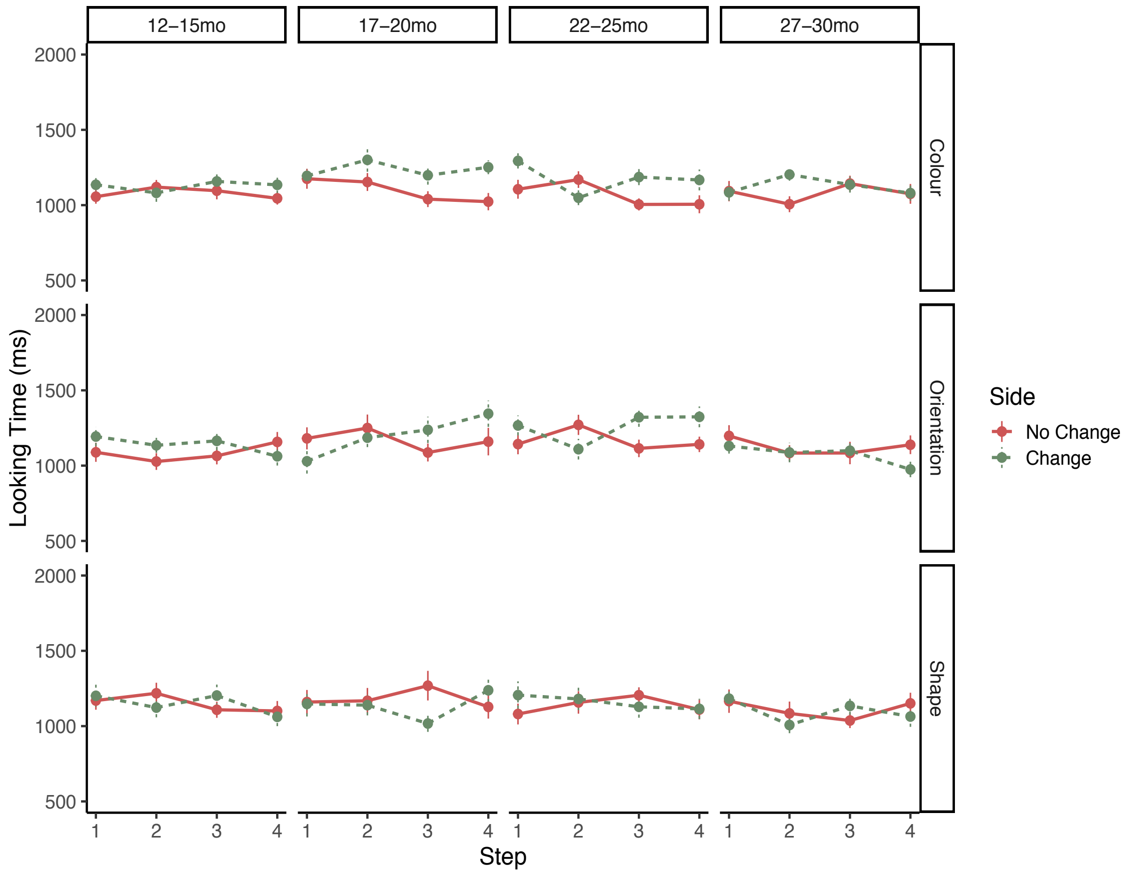

Figure 19. Looking to the change and no change side by dimension and step size across age group in child participants

Analysis of individual dimensions

For the all three dimensions, log likelihood tests indicated the best fitting model only included random effects for subject. For the shape dimension, log likelihood tests suggested the best fitting model contained fixed effects for only side, however there was not a significant effect of looking to the change side, $t(968.11)=-0.36$, $p=0.72$. This suggests that participants did not discriminate the beastie objects based on the changes in the shape dimension.

For the colour dimension, log likelihood tests indicated the best fitting model included a three-way interaction between side, step, and age group. There was a significant main effect of side, such that participants looked more to the change side, $t(969.53)=4.55$ $p<0.001$. There was a significant three-way interaction between side, step, and age group, such that 22- 25-month-old children spent more time looking to the change side on step 2 compared to step 1, $t(968.56)=-2.28$, $p<0.05$. The colour results suggest that children are able to discriminate the beastie objects as they looked significantly longer to the change side. The three-way effect between side, step, and age suggest that the 22 -25-

month-old children were better at detecting the change in the colour dimension as step as the degree of change increased from 15 to 30 degrees.

For the orientation dimension, log likelihood tests indicated the best fitting model included a three-way interaction between side, step, and age group. There was no significant main effect of side, $t(971.01)=1.43$, $p=0.15$, indicating that children were not able to discriminate the orientation changes in the beasties, overall. However, there was a significant two-way interaction between side and step, such that participants had a significant increase in looking to the change side as step increased from 2 to 3, $t(971.32)=-2.01$, $p<0.05$ and a two-way interaction between side and age group, such that participants had significantly more looking to the change side for 22-25-month-olds compared to 27-30-month-olds, $t(971.10)=2.26$, $p<0.05$. In addition, there were two significant three-way interactions between side, step, and age groups, where 17-20-month-olds looked more to the change side as step increased from step 2 to 3, $t(972.32)=2.91$, $p<0.01$ and step 3 to 4, $t(970.89)=2.51$, $p<0.05$. Although the results did not indicate overall discrimination on the orientation dimension, it appears depending on age and step children were able to discriminate the beasties within the orientation dimension. In particular, 22-25-month-olds are able to discriminate changes in the orientation of the beasties and children are better able to discriminate as step increase from 2 to 3. These results indicate that older children and larger steps are needed to be able to discriminate differences in the orientation of objects. These results are interesting as the oldest age group and last step change are not discriminated, which should be the easiest step. However, we did find that as step increased and the degree of change became larger 17-20-month-old children were better able to discriminate the orientation objects.

The individual dimension analysis results revealed children were not able to discriminate on the shape dimension but were able to discriminate on the colour and orientation dimension. It should be noted that 22-25-month-old children discriminated regardless of step, but 17-20-month-old needed larger step changes to discriminate the change. Therefore, some of these effects might have been driven by the middle two age groups (17-20 mo & 22-25 mo), thus we are going to investigate age groups separately to identify age related effects of discriminate of the beasties.

Analysis of individual age groups

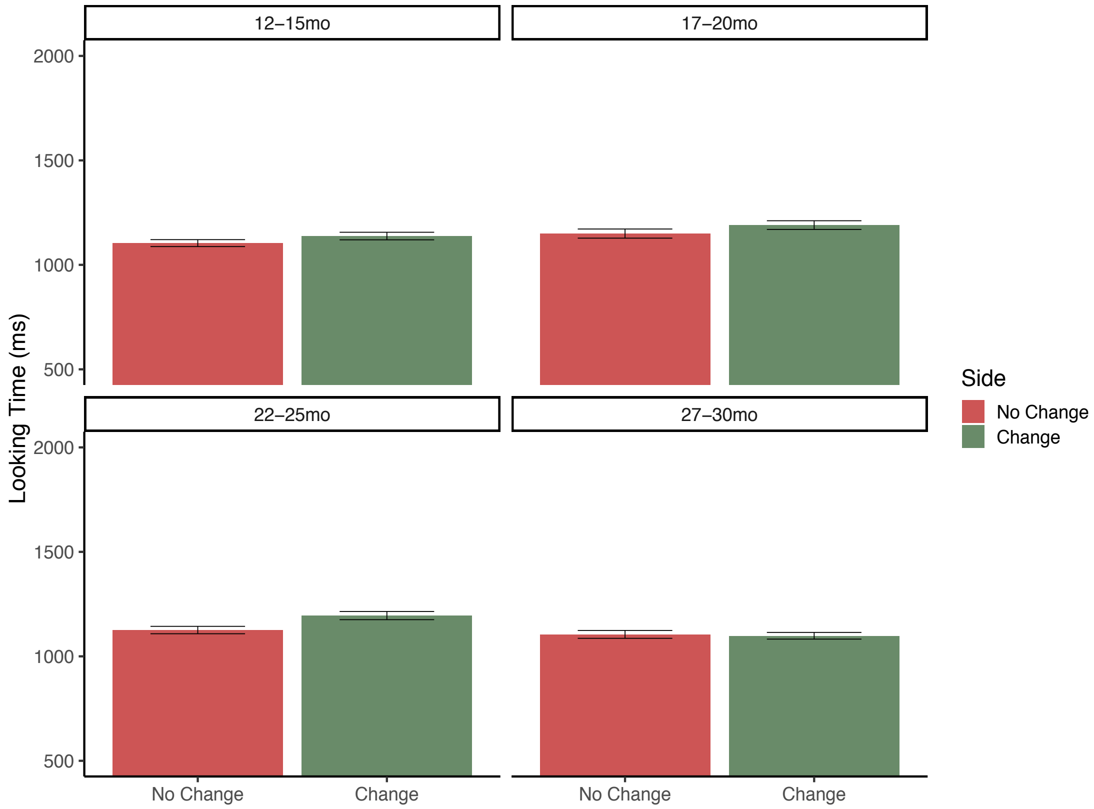

Figure 20. Looking to the change and no change side across age groups

For the youngest and oldest age group, 12-15-month-olds and 27-30-month-olds, log likelihood tests indicated the best fitting model contained random effects for subject and fixed effects for side. For 12-15-month-olds and 27-30-month-olds, there was no significant main effect of side, $t(952.89)=1.60$, $p=0.11$ and $t(772.34)=-0.34$, $p=0.73$. The best fitting model for children aged between 17-20-month-olds contained random effects for subject and fixed effects for dimension, step, and side, with a two-way interaction between side and step and a two-way interaction between side and dimension. There was a significant two-way interaction between side and dimension, where participants had significantly more looking to the change side for colour than shape, $t(731.97)=2.68$, $p<0.01$. There was a significant two-way interaction between side and step, where participants had significantly more looking to the change side for step 2 compare to step 1, $t(731.89)=-2.04$, $p<0.05$, step 3 compare to step 2, $t(731.89)=-2.19$, $p<0.01$ and step 4 compared to step 3, $t(731.92)=-2.89$, $p<0.01$. The best fitting model for participants aged between 22-25-months, contained random effects for subject and fixed effects for dimension, step, and side, with a two-way interaction between side and step. The model revealed a main effect for side, such that participants looked longer to the change side, *t*(730.15)=2.81, *p*<0.01 and a main effect for dimension, where participants looked longer on trials that contained orientation dimension changes compared to trials with shape changes, *t*(730.09)=2.95, *p*<0.01 and looked longer on trials that contained shape changes compared to trials with colour changes, *t*(730.13)=-2.25, *p*<0.05. These age results show that the middle two age groups were able to discriminate the beasties objects, whereas the youngest and oldest age groups were not. The middle two age groups did better as step increased, which was not seen for the youngest and oldest age group. The participants in the 17-20-month-old age range were able to discriminate objects in the colour dimension.

The results from the child participant data were far less robust than the adults suggesting that infants had a harder time discriminating the beastie objects. In particular, there is evidence that the infants were able to discriminate colour changes overall, with more looking to the change side. However, there was no evidence that the infants were able to discriminate changes in the shapes of the beasties. The orientation dimension model results show that participants did not discriminate changes in the orientation of the beasties overall, but certain age groups were able to discriminate depending on step size. In particular, 22-25-month-old children were able to discriminate the orientation objects and 17-20-month-old children were able to discriminate the orientation objects for step 3 and 4, which were the largest change on degrees. Lastly, the age analyses suggested the youngest age group, 12-15mo-olds and oldest age group, 27-30-month-old children, were not able to discriminate the beasties, whereas the middle age groups, 17-20mo-olds and 22-25-month-olds were able to discriminate. In addition, 17-20-month-olds were better able to discriminate as step increased in all four step changes. Overall these results show that children find colour easier to discriminate relative to shape and orientation, but as children get older and as the objects have greater degrees of change this enables younger children to discriminate and all ages to discriminate changes in the orientation of the stimuli. We next examined the visual exploration of the children participants, as we did with adults.

Follow up Models (Visual exploration)

In adults, we found that sampling on the memory and test array was related to more looking to the change side and that looking with in the bottom AOI was related to higher rates of looking to change side for the shape dimension. Therefore, we examined how children's patterns of sampling of the memory and test array and AOI looking were related to discrimination performance. Sampling was coded dichotomously to indicate whether participants looked at both the right and left sides of the memory array. For adults, discrimination performance on the shape dimension was related to having looked at the bottom portion of the beastie. We examined whether children showed a similar effect, although we thought it possible that the fact the eyes of the Beastie were in the top AOI might draw their attention.

Our main questions were the same as in the prior investigation with adults: 1) does looking to both images on the memory array, sampling, lead to differences in looking to the change v. no change side of the test array, 2) does sampling lead to differences in looking to the change v. no change side of the test array 3) does looking to the top or bottom half of the beastie relate to differences in test array looking. Sampling was effect coded to compare participants who did not look to both sides on the memory or test array to those who did.

Sampling Images during Memory Array

The model predicted looking on the test array from side, sampling on memory array, dimension and step. Log likelihood tests indicated that the best fitting random effects structure contained random intercepts for subject and the fixed effects justified by the data included a two-way interaction between dimension and sampling of the memory array. This two- way interaction between dimension and sampling was significant, where was significantly more looking on unsampled trials in the orientation dimension, $t(3414.13)=-2.85$, $p<0.01$ (see Figure 21).

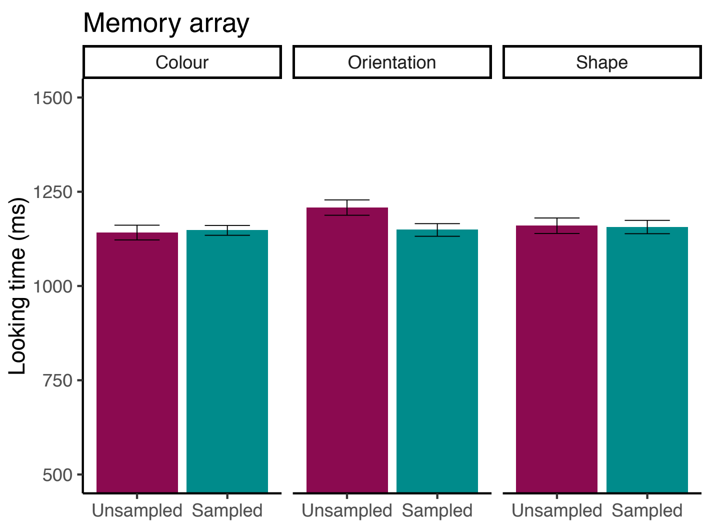

Figure 21. Looking time to sampled and unsampled trials, across the three dimensions on the memory array.

Overall, these results indicate that sample on the memory did not affect looking to the change side on the test array or discrimination ability in children as it did with adult participants. It also appears that sampling had no effect on looking depending on age or step change. The only variable that sampling interacted with was dimension and in particular overall looking to the orientation dimension. On average children sampled the memory array 53% of the time, this also did not vary across dimension (colour:58%, orientation: 52%, shape: 49%) or age group (12-15mo: 55%, 17-20mo: 55%, 22-25mo:50%, 27-30mo:53%). If infants are not significantly sampling the memory this may be an earlier indicator that they are not building visual exploration patterns of looking back and forth that will aide in discrimination on the test array and therefore lead to less overall discrimination of the beasties. In the adult analysis, sampling of the memory was related to looking at the change side on the test array, arguably because sampling of the memory array created a pattern of visual exploration that carried through on to the test array. Therefore, we also investigated if sampling on the test array was related to discrimination.

Sampling Images during Test Array

To answer the second question, does looking to both images on the test array lead to differences in looking to the change versus no change side of the test array, we created a model that predicted looking on the test array from side, sampling on test array, dimension and step. Log likelihood tests indicated that the best fitting random effects structure contained random intercepts for subject and the fixed effects justified by the data included one three-way interaction of side, sampling, and dimension and another three-way interaction of dimension, age group, and sampling. There was a significant main effect of sampling of the test array, such that participants looked more on sampled test trials than unsampled test trials, $t(4755.44)=-14.38$, $p<0.001$. There was a significant two-way interaction between sampling and dimension, with significantly more overall looking on sampled trials for the colour dimension compared to the shape dimension, $t(2888.95)=3.59$, $p<0.001$. There was a significant two-way interaction between sampling and age group, where 27-30-month-olds had less overall looking compared to 22-25-month-olds on unsampled trials, $t(4740.47)=-3.06$, $p<0.01$. There was a significant three-way interaction between side, dimension, and sampling on test trials, such that participants looked more to the change side on sampled trials for the colour dimension, $t(4695.13)=2.66$, $p<0.01$. There was an additional significant three-way interaction between dimension, age group, and sampling, such that 22-25-month-olds looked more sampled trials for the orientation dimension, $t(4690.61)=-2.61$, $p<0.01$.

Figure 22. Looking time to change and no change side by sampled and unsampled trials, across the three dimensions on the test array.

Although we did not see much in terms of sampling on the memory array, sampling on the test array provided more insight into the how looking behaviours of the children related to discrimination. On average children sampled the test array 61% of trials, which is an increase from their average sampling of the memory array. The percentage did not vary much across age (12-15mo: 60%, 17-20mo: 59%, 22-25mo:63%, 27-30mo:63%), but did across dimension (colour:70%, orientation: 60%, shape: 57%) with colour having the highest percentage of sampling. The model suggested that sampling on the test array was related to discrimination (looking to change side) as it interacted with dimension. The overall model indicated that infants looked significantly more to the change side for the colour dimension when the infants had sampled both test images. This may mean that sampling the test images does help children to identify the changed object, at least for colour. Participants that sampled the test array had significantly more looking for the colour dimension trials, which was previously found to be discriminated by child participants in the overall proportion analysis and was the dimension which had the highest proportion of sampling. In adult participants there was a relationship found between sampling of the test images and discrimination. It may be that this same relationship is evident in children, particularly for the colour dimension, but as discrimination results were far less robust than that of adults this relationship may be weaker. There was also some evidence that sampling the test images varied depending on dimension and age. The interaction of sampling of the test images with age, the results revealed the oldest age group, 27-30-month-olds, had significantly less overall looking compared to 25-27-month-olds on sampled test trials. From our previous age group analysis, we found that 25-27-month-olds were able to discriminate the beastie objects, unlike the oldest participants, 27-30-month-olds. Together these results suggest there may be a relationship between sampling of the test images and discrimination as there was with adult participants, however unlike adult participants, the child data indicated that it is less robust and may vary by age and dimension. Next, we tested whether the location of where participants looked is related to change side looking.

Areas of Interest: Top/Bottom

To examine the relation between looking to particular areas of the stimuli and discrimination we created a model that included change look, dimension, step, and AOI (top and bottom). Log likelihood tests indicated that the best fitting random effects structure contained random intercepts for subject and the fixed effects justified by the data included a four-way interaction of side, dimension, step, and AOI and a two-way interaction between age group and AOI. There was a main effect of AOI, were there was more looking in the top AOI, $t(5972.21)=-5.61$, $p<0.001$. There was a significant two-way interaction between looking to the change side and area of interest with more looking to the change side for the top AOI, $t(5944.91)=-3.84$, $p<0.001$. There is a significant two-way interaction between AOI and age group, with significantly more looking to the top AOI for 22-25-month-olds compared to 27-30-month-olds, $t(5966.07)=-2.28$, $p<0.05$. There was a significant two-way interaction between AOI and dimension, where there was more looking to the top AOI for colour, $t(5945.28)=-6.89$, $p<0.001$ and orientation, $t(5944.82)=-12.93$, $p<0.001$ compared to shape. There were two three-way interactions: between looking to the change side, step, and AOI, such that participants significantly decreased looking to the change side within the top AOI for step 3 to compared to step 2, $t(5944.09)=-4.02$, $p<0.001$, and for step 4 compared to step 3, $t(5944.35)=-4.78$, $p<0.001$. There was a significant three-way interaction between side, dimension, and AOI, such that participants had more looking to the change side that fell within the top AOI for the colour dimension compared to the shape dimension, $t(5943.74)=4.21$, $p<0.001$. There was a significant three-way interaction between AOI, step, and dimension, with more looking within the top AOI for orientation compared to shape for step 3 compared to step 2, $t(5944.14)=-2.63$, $p<0.01$ and step 4 compared to step 3, $t(5944.42)=-3.53$, $p<0.001$. Lastly, there was a significant four-way interaction between side, dimension, step, and AOI. To investigate this interaction the shape dimension was analysed separately, as it significantly differed from both colour and orientation.

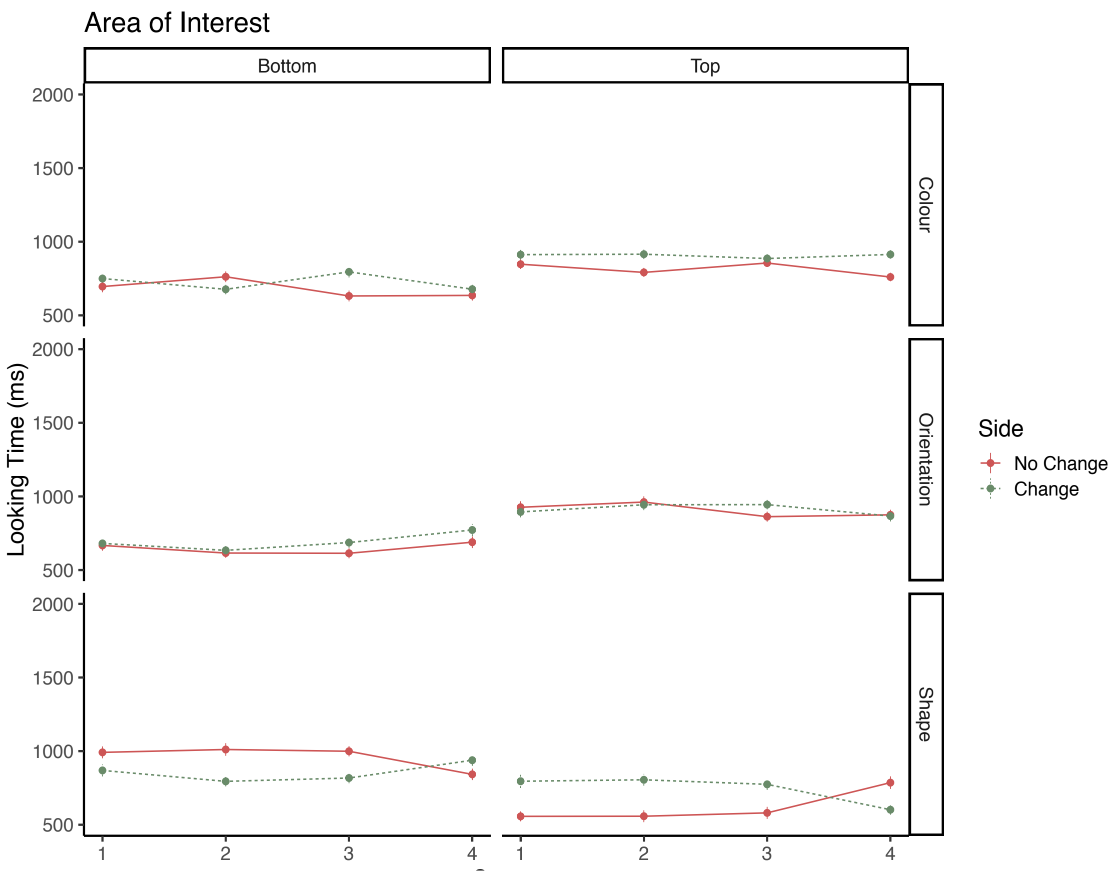

Figure 23. Looking time to change and no change side for the bottom and top interest areas, across dimension.

The shape model included change side, step, and AOI (top and bottom). Log likelihood tests indicated that the best fitting random effects structure contained random intercepts for subject and the fixed effects justified by the data included a three-way interaction of change look, step, and AOI. There was a main effect of AOI, with more looking to the bottom AOI, $t(1846.75)=11.70$, $p<0.001$. There was a significant two-way interaction between AOI and side, such that participants looked more to the change side within the top AOI, $t(1821.33)=-5.94$, $p<0.001$. There was a significant three-way interaction between side, step and AOI, there was a significant increase in looking to the change side within the bottom from step t to 1 to 2, $t(1815.68)=-2.03$, $p<0.05$, step 2 to 3, $t(1815.79)=-4.83$, $p<0.001$ and 3 to 4, $t(1818.38)=-7.73$, $p<0.001$.

These analyses reveal that the relation between looking to specific parts of the stimuli and discrimination depends on the dimension tested. Overall, children looked more to the top half of the stimuli, which contains the beastie's eyes. This fits with literature suggesting children prefer to look at faces and face-like features (Cassia, et al, 2004; Johnson, et. al., 1991). This preference was seen for the colour and the orientation dimensions. For the orientation dimension this preference has no effect on discrimination, but it did affect discrimination for the colour dimension. For the colour dimension, participants had an increase in looking to the change side for the top half of the beastie stimuli as step changed from 1 to 2 or the degree of change increased from 15-degrees to 30-degrees. Looking in the top half may have aided participants in discriminating the colour dimension, but this may not be a strong pattern as it only happened for one step. The looking pattern for the shape dimension was the complete opposite.

For shape trials, participants preferred to look to the bottom half of the beasties, which contained the leg features. This preference was also related to discrimination, as infants looked more to the top portion of the changed stimulus overall except for the greatest degree of change, 60 degrees or step 4. In this case, infants looked more overall to the bottom portion of beasties but looking to the bottom only added in discrimination for the easiest or biggest step change. The results from the adults suggested that looking to the bottom half of the beasties was related to more looking to the change side. As we argued with the adult participants, the bottom AOI, which contained the leg features, could provide a point of reference to help see the shape change (see Figure 18). However, there is a large difference between that of children and adults, adults were able to discriminate changes in the beasties across all three dimensions and with even the smallest step, whereas children did demonstrate significant discrimination overall. Taken together, children did replicate some looking effects of adults with more looking in the bottom AOI for shape, but this is again tempered by differing discrimination rates; children may have overcome their preference to look at face features for shape, but not enough to gain the benefits and discriminate.

3.3.3 Discussion

Children's ability to discriminate the beasties was far less robust and systematic than that of the adults. Although, overall children looked more to the change side of the test array, possibly indicating discrimination, discrimination did not improve as the degree of change between the objects increased, as it did with adults. When each dimension was examined separately, it was found that colour was the only dimension that had longer looking to the change side, whereas shape and orientation did not, although depending on age and step children were able to discriminate orientation object. As for age, children in the youngest and oldest age groups (12-15mo and 27-30mo) did not have significantly more looking to the change side. In contrast, the middle two age groups (17-20mo and 22-25mo) were able to discriminate the beasties, but the patterns of discrimination ability across age and step did not gradually increase.

When we investigated children's visual exploration, we did not see the same robust patterns we saw in the adult data. Sampling of the memory array did not have any impact on discrimination at test, but there was an effect of whether infants sampled the test array. Children who sampled the test array for the colour dimension looked more to the change side. The sampling behaviour in and of itself was different for age group and dimension, however neither influenced looking to the change side. These results suggest it is beneficial for the children to sample the beasties on the test array, but only this was only beneficial for the colour dimension.

Lastly, the analysis of what part of the stimuli children looked at revealed that adults and children had a similar pattern. Children looked at the top of the beasties more, arguably because that contained the eyes. It may be that since the top half had the eyes, it kept children's interest, which resulted in better encoding of the colour stimuli and thus more discrimination. Children also preferred to look at the top of the beasties on the orientation trials, however in this case there was not a significant interaction with change side and thus their looking to the top half did not result in better discrimination. This may be because orientation was a dimension that was overall harder to discriminate or because the top half of the beasties did not provide any additional information aide in discrimination. For shape trials, children looked at the bottom more than the of the top of the beasties. However, this did not appear to result in reliable discrimination, and numerically looking to the change side was higher when children looked more at the top of the stimuli suggesting that looking to the bottom AOI did not support discrimination ability as it did with adults.

Overall, these results do not provide strong support for the claim that children are able to discriminate the differences in the beastie stimuli. The fact that they looked more overall to the changing side is encouraging, but we did not see this uniformly across dimensions, nor did we see a systematic improvement with increasing stimulus changes or age. With this said, children did evidence some ability to discriminate changes in the colour of the beasties. Given that colour was one of the two features of the beasties that differed among the six stimuli used in the cross-sectional word learning studies, there is then some possibility they could tell the stimuli apart.

However, it is also possible that the weak and unsystematic nature of our findings in this experiment results from our use of total accumulated looking across the entire test array (3000 ms) as our dependent measure. It may be that not having a fixation stimulus prior to the test array, resulted in children starting the test array already looking to and accumulating time on a beastie, only for them to switch to the preferred beastie, thus evening out their looking time. Given that children and infants of this age can make between 3 to 4 fixations in this amount of time, it is possible that a cumulative measure such as ours masks important information about infants looking dynamics.

Therefore, we reran the child participant data through Eyetracking R (Dink & Ferguson, 2015) to identify if there were more systematic underlying looking patterns that developed over the time course of the trials that might have been lost through our previous analysis. With this said, we do not believe the previous analysis was incorrect, but moreover we believe that some of the looking patterns might be lost when preforming a higher-level analysis combining all individual looks. We also do not believe adults need to be ran in this type of analysis as there looking patterns were quite robust.

3.3.4 Results 2

Analysis

Children's time course data was extracted out of Dataviewer. This data is the moment to moment record of where children are looking sampled every 2 ms. The time course data provides a more detailed account of what children are doing over the course of the trial. Data was then analysed in the Eyetracking R package (Dink J, Ferguson B., 2015) and through the use of logistic mixed effects models with R package glmmPQL. The following analysis examines the proportion of time infants spent looking at the change side divided by the total looking to either side during each 2 ms bin of the 3000 ms test array trial. Data from each dimension was investigated individually with models that included random effects for subject with fixed effects for step and age group. In addition, we created a new variable called first look, that coded whether an infant was looking at the change side versus the no change side at the start of the trial. We reasoned that if infants can detect the change in a stimulus, their pattern of looking over the course of the trial will be different depending on where they were looking at the start of the trial. Infants who start the trial looking at the no change side should be more likely to switch to look at the change side, whereas infants who are already looking at the change side should be more likely to maintain looking to that side. First look was included as a fixed effect and all fixed factors were effects coded.

The shape and orientation data follow a curved trend with one peak; therefore, the time course data was modelled using a second order (quadratic) orthogonal polynomial. The data for the colour dimension follows a curved trend with two peaks, thus it was modelled with a third order (cubic) orthogonal polynomial. The shape and orientation models examine children's fixation patterns over time point one (linear) and $time^2$ (quadratic), while examining the effects of step, age group, and first look location on patterns of fixation. The colour model examines children's fixation patterns over time point one (linear), $time^2$ (quadratic), and $time^3$ (cubic), examining the effects of step, age group, and first look location on patterns of fixation.

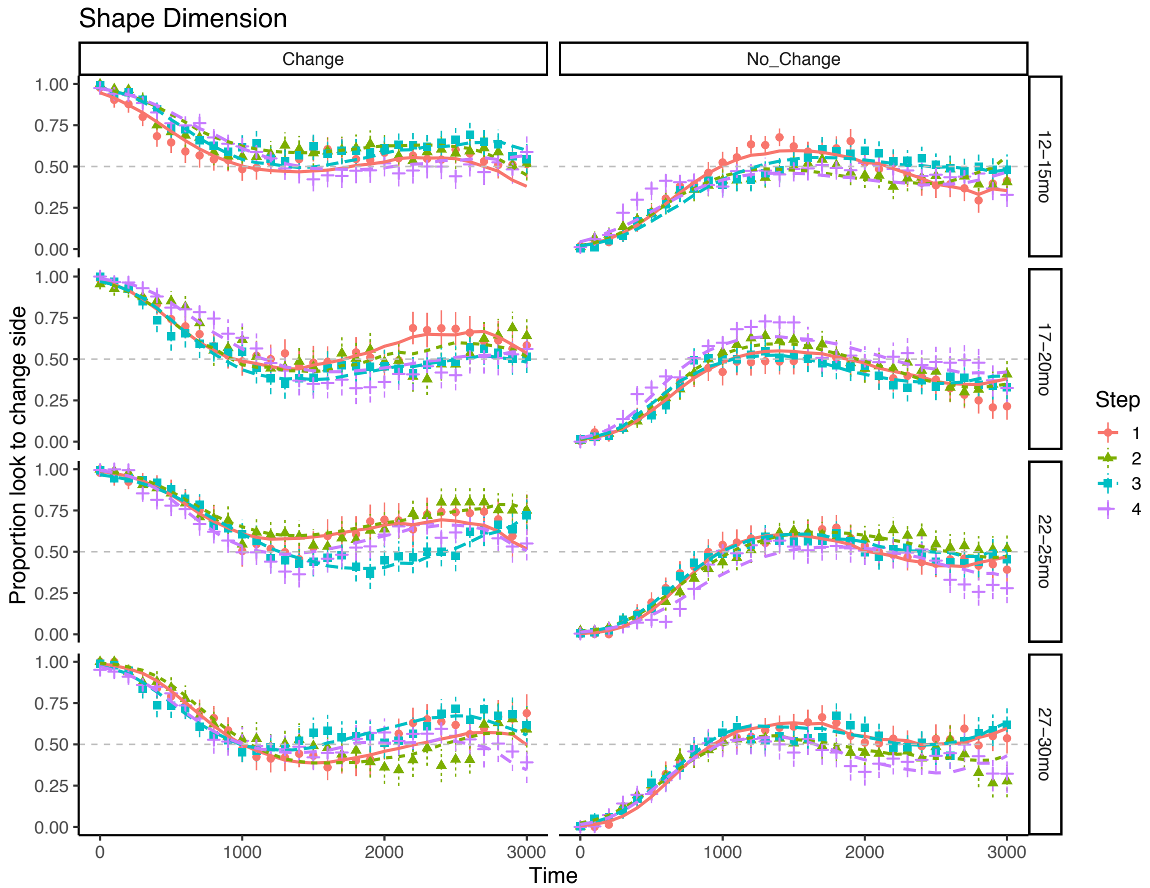

Figure 24. The time course of fixations for each of the Step changes (1,2,3,4) during the test array, separated by first look location (change side v. no change side) for all four age groups (12-15mo, 17-20mo, 22-25mo, 27-30mo). The dotted line indicates chance looking at 50%.

The previous analysis of overall looking to the change and no change sides for the shape dimension suggested that children did not look significantly longer to the change side compared to the no change side. These results indicated that children were unable to discriminate the beasties based on the shape dimension regardless of age group or degree of change (step). However, the time course data (see Figure 24), reveal a more complex pattern of looking that suggests over the trial time children are making significant shift to the change side indicating signs of discrimination. In addition, the time course data suggests that where the infants were looking at the start of the trial does influence their looking pattern.

Children who were looking to the change when the test array started gradually shifted to look at the no change side by around a 1000 ms. However, over the remaining 2000 ms it appears as though they shift their looking back to the change side and possibly once more to the no change side. Children who start their first look in the no change side show the opposite pattern. They gradually shift to the change side by around 1000 ms followed by a look back to the no change side and possibly a last shift to the change side. Although both groups show a similar trend of looking back and forth between the change side and no change side, where they started had a significant effect on their proportion looking to the target. The model coefficients show that children who start the trial looking to the change side had significantly more looking to the change side, as opposed to participants who first looked to the no change side. The effect of first look can be seen around the 2000 ms time point, when both groups of children shift their looking, children who started looking at the change side return to look at the change side and the children who started looking to the no change side return to look to the no change. This suggests that due to the oscillating nature of children's looking (shifting back and forth) the location where you start at the beginning of the trial may end up accumulating more looking time if the trial ends before they have shifted back to the other AOI.

In addition to the effect of first look location, the model coefficients suggest that there are also main effects for age group and step, as well as interactions between the all three factors. For age group, 22-25-month-old children had a significantly higher proportion of looking to the change side. These participants started to look more to the change side around the 1000 ms time point and continued to maintain looking to this side of the array until the end of the trial. For step, participants shift to look at the change side significantly more with the 30-degree change (step2). For this degree of change, participants began to shift their looking to the change side around 750 ms and did not decrease or shift their looking to the no change side until the end of the trial.

The model coefficient for the interaction between age group and step revealed that 12- 15-month-old children had a significant decrease in looking to the change side for a 15-degree change (step 1) compared to 17-20month-old, whose looking trajectory remained relatively flat with the step 1 change. In contrast, 22-25month-old children showed significantly more looking to the change side when the beasties changed by 30-degrees (step 2). They began to look to the change side around 750 ms and continued to increase their looking throughout the trial. Although older, the 27-30-month children only showed a significantly increase in looking to the change side with the larger change of 45-degrees (step 3).

The interaction between first look and age group, reveals that 22-25-month-old participants who started the test array looking to the change side had significantly more looking to the change side over the course of the trial compared to both their younger (17-20mo) and older (27-30mo) counterparts. The interaction between first look and step was caused by a significant increase in looking to the change side with a 30-degree (step 2) change compared to a 15-degree (step 1) change for participants who started the test array looking at the change side. However, this increase in looking to the change side was not seen with the larger step changes. Also, participants who started their first look to the change side looked more to the change side for 45-degree (step 3) compared to a 60-degree (step 4) change.

The model coefficient for the three-way interaction revealed three effects of step, age group, and first look. First, 17-20-month-old children who started the trial on the change side showed a significant increase in looking to the change side for the lowest step change of 15-degrees around 1500 ms and continued in this trajectory until 2800 ms. Second, 22-25-month-old children who started the trial on the change side showed a significant increase in looking to the change side for a 30-degrees step change (step 2) around 1500 ms and continued in this trajectory until the end of the trial. Third, 27-30-month-old children who started the trial on the change side showed a significant increase in looking to the change side for a 45-degrees step change (step 3) around 1100 ms and continued in this trajectory until 2500 ms.

Overall the shape dimension time course results show that children did have significant shifts in their looking to the change indicating that they were able to discriminate the shape changes in the beasties. Although the shifts in looking to the change side did vary by age, step, and where children were looking at the start of the test array, as children get older and with larger changes, children looked more to the change side. In addition, because children's looking trajectories included around three shifts between looks to the change and no changes side, if they started on the change side, they accumulated more time looking to the change side.

Table 4. Time course analysis model coefficients for the shape dimension

Fixed Effects Shape	*Estimates*	*SE*	*t*	*p*
First Look	1.32	0.02	55.90	<0.001
ot1: First Look	-6.14	0.14	-42.70	<0.001
ot2: First Look	8.52	0.1	55.90	<0.001
Step:1 by 2	-0.01	0.02	-0.37	0.712
2 by 3	0.06	0.02	3.77	<0.001
3 by 4	-0.02	0.02	-0.83	0.409
ot1: 1 by 2	0.23	0.12	1.92	0.055
2 by 3	-0.03	0.12	-0.28	0.781
3 by 4	0.22	0.12	1.91	0.056
ot2: 1 by 2	-0.41	0.13	-3.18	<0.01
2 by 3	0.12	0.13	0.91	0.362
3 by 4	0.26	0.12	2.06	<0.05
Age Group:12-15mo by 17-20mo	-0.04	0.06	-0.57	0.572
17-20mo by 22-25mo	-0.09	0.07	-1.36	0.178
22-25mo by 27-30mo	0.14	0.07	2.05	<0.05
ot1: 12-15mo by 17-20mo	-0.15	0.32	-0.45	0.650
17-20mo by 22-25mo	-0.43	0.35	-1.22	0.222
22-25mo by 27-30mo	0.65	0.35	1.84	0.065

ot2: 12-15mo by 17-20mo	-0.13	0.29	-0.45	0.654
17-20mo by 22-25mo	-0.03	0.31	-0.09	0.927
22-25mo by 27-30mo	-0.03	0.32	-0.10	0.917
First Look: Step: 1 by 2	-0.02	0.41	-0.48	0.628
First Look: 2 by 3	0.15	0.41	3.69	<0.001
First Look: 3 by 4	-0.16	0.40	-4.15	<0.001
ot1: First Look: 1 by 2	0.04	0.25	0.15	0.88
First Look: 2 by 3	0.35	0.25	1.42	0.16
First Look: 3 by 4	-0.21	0.24	-0.85	0.39
ot2: First Look: 1 by 2	0.15	0.26	0.57	0.57
First Look: 2 by 3	0.14	0.27	0.52	0.61
First Look: 3 by 4	-0.10	0.26	-0.38	0.70
First Look: Age Group:12-15mo by17-20mo	0.02	0.04	0.47	0.64
17-20mo by 22-25mo	-0.15	0.04	-3.70	<0.001
22-25mo by 27-30mo	0.33	0.04	7.76	<0.001
ot1: 12-15mo by 17-20mo	0.33	0.23	1.43	0.152
17-20mo by 22-25mo	0.86	0.25	3.43	<0.001
22-25mo by 27-30mo	-1.11	0.26	-4.23	<0.001
ot2: 12-15mo by 17-20mo	-1.27	0.24	-5.29	<0.001
17-20mo by 22-25mo	0.41	0.27	1.54	0.125
22-25mo by 27-30mo	0.67	0.28	2.42	<0.05
Age Group 12-15mo by 17-20mo: Step 1	-0.09	0.03	-2.88	<0.01
Age Group 12-15mo by 17-20mo: Step 2	0.004	0.03	0.12	0.906
Age Group 12-15mo by 17-20mo: Step 3	0.04	0.03	1.30	0.193
Age Group 17-20mo by 22-25mo: Step 1	0.001	0.04	0.04	0.972
Age Group 17-20mo by 22-25mo: Step 2	-0.08	0.03	-2.22	<0.05
Age Group 17-20mo by 22-25mo: Step 3	-0.15	0.03	-4.55	<0.001
Age Group 22-25mo by 27-30mo: Step 1	0.03	0.04	0.70	0.483
Age Group 22-25mo by 27-30mo: Step 2	0.16	0.04	4.30	<0.001
Age Group 22-25mo by 27-30mo: Step 3	-0.06	0.03	-174	0.082
ot1: Age Group 12-15mo by 17-20mo: Step 1	-0.11	0.19	-0.61	0.545
Age Group 12-15mo by 17-20mo: Step 2	-0.06	0.20	-0.31	0.758
Age Group 12-15mo by 17-20mo: Step 3	0.54	0.19	2.85	<0.01
Age Group 17-20mo by 22-25mo: Step 1	0.48	0.21	2.24	<0.05
Age Group 17-20mo by 22-25mo: Step 2	0.31	0.21	1.46	0.144
Age Group 17-20mo by 22-25mo: Step 3	-0.49	0.21	-2.40	<0.05
Age Group 22-25mo by 27-30mo: Step 1	-0.56	0.22	-2.48	<0.05
Age Group 22-25mo by 27-30mo: Step 2	0.60	0.21	2.67	<0.01
Age Group 22-25mo by 27-30mo: Step 3	-0.89	0.20	-4.26	<0.001
ot2: Age Group 12-15mo by 17-20mo: Step 1	-0.45	0.20	-2.28	<0.05
Age Group 12-15mo by 17-20mo: Step 2	-0.06	0.20	-0.31	0.760
Age Group 12-15mo by 17-20mo: Step 3	-0.13	0.20	-0.67	0.504
Age Group 17-20mo by 22-25mo: Step 1	0.28	0.22	1.26	0.209
Age Group 17-20mo by 22-25mo: Step 2	-0.43	0.22	-1.91	0.056
Age Group 17-20mo by 22-25mo: Step 3	0.19	0.22	0.89	0.373
Age Group 22-25mo by 27-30mo: Step 1	-0.32	0.24	-1.35	0.178
Age Group 22-25mo by 27-30mo: Step 2	0.16	0.24	0.66	0.508
Age Group 22-25mo by 27-30mo: Step 3	0.11	0.22	0.47	0.638
First Look:Age Group 12-15mo by 17-20mo: Step 1	-0.25	0.06	-3.89	<0.001
Age Group 12-15mo by 17-20mo: Step 2	0.09	0.07	1.36	0.175
Age Group 12-15mo by 17-20mo: Step 3	0.12	0.06	1.88	0.060
Age Group 17-20mo by 22-25mo Step 1	0.22	0.07	3.12	<0.01
Age Group 17-20mo by 22-25mo: Step 2	-0.12	0.07	-1.66	0.097
Age Group 17-20mo by 22-25mo: Step 3	0.07	0.07	0.96	0.335
Age Group 22-25mo by 27-30mo: Step 1	0.14	0.08	1.83	0.067
Age Group 22-25mo by 27-30mo: Step 2	0.01	0.07	0.15	0.884
Age Group 22-25mo by 27-30mo: Step 3	-0.31	0.07	-4.40	<0.001
ot1: First Look: Age Group 12-15mo by 17-20mo: Step 1	0.90	0.39	2.34	<0.05
First Look: Age Group 12-15mo by 17-20mo: Step 2	-0.22	0.40	-0.55	0.581
First Look: Age Group 12-15mo by 17-20mo: Step 3	-0.48	0.39	-1.21	0.226
First Look: Age Group 17-20mo by 22-25mo: Step 1	0.29	0.43	0.66	0.508
First Look: Age Group 17-20mo by 22-25mo: Step 2	0.94	0.43	2.17	<0.05
First Look: Age Group 17-20mo by 22-25mo Step 3	0.31	0.43	0.73	0.467
First Look: Age Group 22-25mo by 27-30mo: Step 1	0.42	0.47	0.90	0.368
First Look: Age Group 22-25mo by 27-30mo: Step 2	0.04	0.45	0.08	0.935
First Look: Age Group 22-25mo by 27-30mo: Step 3	-0.97	0.43	-2.27	<0.05
ot2: First Look: Age Group 12-15mo by 17-20mo: Step 1	0.78	0.41	1.92	0.054
First Look: Age Group 12-15mo by 17-20mo: Step 2	-1.17	0.42	-2.81	<0.01
First Look: Age Group 12-15mo by 17-20mo: Step 3	0.70	0.41	1.69	0.091
First Look: Age Group 17-20mo by 22-25mo: Step 1	-0.30	0.46	-0.67	0.506
First Look: Age Group 17-20mo by 22-25mo: Step 2	0.44	0.46	0.96	0.339
First Look: Age Group 17-20mo by 22-25mo: Step 3	-0.64	0.45	-1.42	0.155
First Look: Age Group 22-25mo by 27-30mo: Step 1	-0.93	0.49	-1.90	0.058
First Look: Age Group 22-25mo by 27-30mo: Step 2	0.22	0.48	0.45	0.655
First Look: Age Group 22-25mo by 27-30mo: Step 3	0.23	0.46	0.51	0.613

"ot" refers to the orthogonal time terms, such that ot1 refers to the linear term and ot2 the quadratic

The previous results of the analysis of overall looking for the orientation dimension suggested that children did not show a significant difference in looking to the change and no change sides of the test array. However, interactions between side, step, and age groups revealed that at certain ages (17-20mo and 22-25mo) and larger step changes (step 3-27 degrees and step 4-36 degrees) did result in more looking to the change, and thus some ability to discriminate changes in the orientation of the stimuli. Looking at the time course data (see Figure 25), suggest changes in looking is influences depending on where children were looking at the start of the trial.

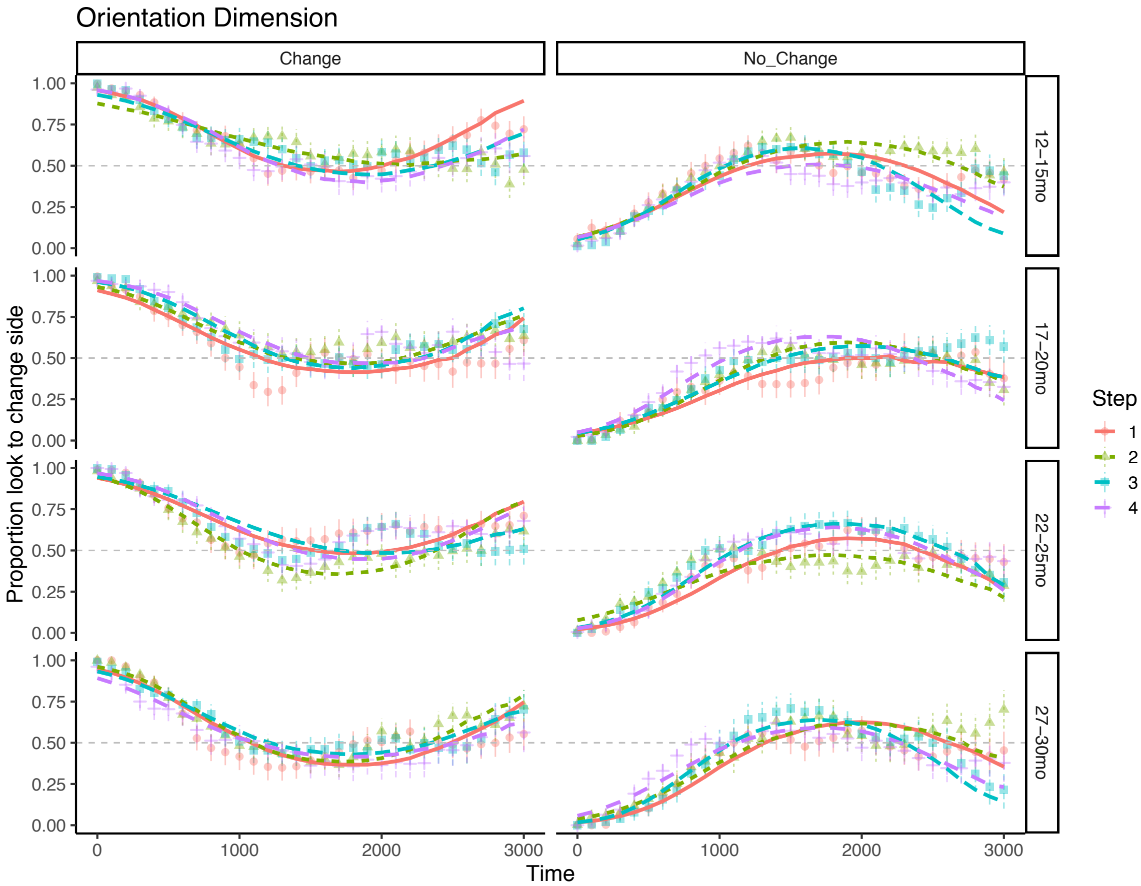

Figure 25. The time course of fixations for each of the Step changes (1,2,3,4) during the test array, separated by first look location (change side v. no change side) for all four age groups (12-15mo, 17-20mo, 22-25mo, 27-30mo). The dotted line indicates chance looking at 50%.

Children who were looking to the change side of the test array at the start, had a gradually shifted to look at the no change side around an 1800 ms. Over the remaining 1500 ms it appears they shifted their looking back to the change side, generating two shifts in looking. Conversely, children who started the test array looking to the no change side, gradually shifted to the change side, also around 1800 ms, followed by a look back to the no change side. Both groups show a similar trend of looking back and forth between the change side and no change side, but with opposite patterns. The model coefficients indicate that children who start the trial looking to the change side had significantly more looking to the change side, as opposed to participants who first looked to the no change side.

In addition, the model coefficients suggest that there is also a main effect step, along with interactions between age and step, step and first look, as well as a three-way interaction. For step, participants looked significantly less to the change side for a 9-degree change (step1) in the orientation dimension compared to an 18-degree change (step2). Over the time course, participants showed more looking to the no change side for step 1. This looking trajectory continues until 2100 ms, when participants gradually increased their looking to the change side.

The model coefficients for the interaction between age group and step revealed that 12-15-month-old children had a significant increase in looking to the change side for an 18-degree change (step 2) compared to 17-20-month-olds. In contrast, 17-20-month-old children showed a significant decrease in their looking to the change side with a 9-degree change (step1), but significant increase in their looking for a 36-degree change, indicating that they could not discriminate the orientation changes until the largest step change. The 22-25-month-old children showed significantly less looking to the change side when the beasties changed by 18-degrees (step 2), but significantly increased their looking to the change side over the course of the trial for a 27-degree step change. These results indicate that over the course of the trial some age groups are able to detect the change in orientation, but often need a larger degree (step) change to shift their looking to the change side.

The interaction between first look and step revealed that children who started the test array looking at the no change side had a slower rate of shifting to the change side for the 9-degree step change. This effect indicates that children had a harder time discriminating the smallest degree changes for orientation. The interaction between first look and age group, reveals that 27-30-month-old participants who started the test array looking to the change side had a significantly slower rate of shifting their looking throughout the course of the trial. This suggests that 27-30-month-olds were not only slower to shift their looking to the no change side, but also took longer to shift their looking back to the change side.

Several effects drove the three-way interaction between step, age group and first look. For the youngest age group, 12-15-month-old participants, those who started the test array looking to the change side a had significant increase in looking to the change side for a 9-degree change (step 1) occurring around 2000 ms. Conversely, 12-15-month-old participants who started the test array looking to the no change side, had a significant increase in looking to the change side for an 18-degree change (step 2) around 1600 ms. This result suggests that 12-15-month-old children who start looking at the no change side may need a larger step size to notice the orientation change compared 12-15-month-old children who started on the change side. The 22-25-month-old children who started the trial looking to the change side showed a significant shift in looking back to the change side for a 9-degrees change (step 1). Their 22-25-month-old counterparts who started the trial looking to the no change side, however, had a higher rate of shifting their looking to the change side for a 27-degree change (step 3) over the trial. The three-way results show how children’s looking over the course of the trial can shift depending on the step of change and the age range of the participants. Some children are able to shift to the change side fairly quickly with a smaller step change, where as other children need a larger degree (step 4) change to push their looking to the changed object.

Overall, the time course results for the orientation dimension showed children were able to discriminate the orientation changes in the beasties. As with the shape dimension, children who started the test array looking to the change side showed higher rates of discrimination. Yet, even some of the children who started the test array looking at the no change side were able to shift their looking to the change side over time, especially on trials that included larger degree (step) changes in orientation. However, while there were significant differences in the looking behaviours for the different age groups; these were not systematic enough to conclude that older children discriminate at higher rates than younger children, suggesting there is not an age related difference in discrimination ability for the orientation beasties between 12- 30-month-old children.

Table 5. Time course analysis model coefficients for the Orientation dimension

Fixed Effects Orientation	*Estimates*	*SE*	*t*	*p*
First Look	1.31	0.02	57.57	<0.001
ot1: First Look	-6.75	0.14	-48.32	<0.001
ot2: First Look	8.50	0.15	57.53	<0.001
Step:1 by 2	-0.05	0.02	-2.74	<0.01
2 by 3	0.005	0.02	0.24	0.808
3 by 4	0.02	0.02	1.28	0.202
ot1: 1 by 2	0.64	0.12	5.43	<0.001
2 by 3	0.30	0.12	2.64	<0.01
3 by 4	-0.29	0.12	-2.45	<0.05
ot2: 1 by 2	0.27	0.12	2.15	<0.05
2 by 3	0.30	0.12	2.49	<0.05
3 by 4	-0.52	0.13	-4.15	<0.001

Age Group:12-15mo by 17-20mo	0.06	0.04	1.41	0.161
17-20mo by 22-25mo	0.01	0.05	0.16	0.875
22-25mo by 27-30mo	0.01	0.05	0.26	0.793
ot1: 12-15mo by 17-20mo	-0.66	0.33	-1.98	<0.05
17-20mo by 22-25mo	0.22	0.35	0.62	0.534
22-25mo by 27-30mo	0.02	0.35	0.05	0.962
ot2: 12-15mo by 17-20mo	-0.10	0.27	-0.38	0.705
17-20mo by 22-25mo	0.18	0.28	0.62	0.537
22-25mo by 27-30mo	0.003	0.28	0.01	0.993
First Look: Step: 1 by 2	0.07	0.04	1.71	0.086
First Look: 2 by 3	-0.12	0.04	-3.14	<0.01
First Look: 3 by 4	0.04	0.04	1.13	0.258
ot1: First Look: 1 by 2	-0.43	0.24	-1.80	0.072
First Look: 2 by 3	0.12	0.24	0.51	0.610
First Look: 3 by 4	0.01	0.24	0.04	0.966
ot2: First Look: 1 by 2	-0.06	0.25	-0.22	0.823
First Look: 2 by 3	-0.82	0.25	-3.28	<0.001
First Look: 3 by 4	0.51	0.26	2.01	<0.05
First Look: Age Group:12-15mo by17-20mo	-0.01	0.04	-0.22	0.830
17-20mo by 22-25mo	0.07	0.04	1.69	0.090
22-25mo by 27-30mo	0.10	0.04	2.65	<0.01
ot1: 12-15mo by 17-20mo	1.22	0.23	5.39	<0.001
17-20mo by 22-25mo	-0.48	0.24	-1.96	<0.05
22-25mo by 27-30mo	-0.55	0.24	-2.29	<0.05
ot2: 12-15mo by 17-20mo	-0.43	0.24	-1.81	0.071
17-20mo by 22-25mo	-0.37	0.26	-1.46	0.146
22-25mo by 27-30mo	0.14	0.25	0.54	0.587
Age Group 12-15mo by 17-20mo: Step 1	0.18	0.03	5.80	<0.001
Age Group 12-15mo by 17-20mo: Step 2	0.09	0.03	2.85	<0.01
Age Group 12-15mo by 17-20mo: Step 3	-0.10	0.03	-3.28	<0.01
Age Group 17-20mo by 22-25mo: Step 1	-0.16	0.03	-4.63	<0.001
Age Group 17-20mo by 22-25mo: Step 2	-0.02	0.03	-0.70	0.486
Age Group 17-20mo by 22-25mo: Step 3	0.03	0.03	1.00	0.332
Age Group 22-25mo by 27-30mo: Step 1	-0.01	0.03	-0.40	0.695
Age Group 22-25mo by 27-30mo: Step 2	-0.18	0.03	-5.57	<0.001
Age Group 22-25mo by 27-30mo: Step 3	0.12	0.03	3.59	<0.001
ot1: Age Group 12-15mo by 17-20mo: Step 1	-0.03	0.19	-0.14	0.887
Age Group 12-15mo by 17-20mo: Step 2	0.38	0.19	2.05	0.041
Age Group 12-15mo by 17-20mo: Step 3	-0.37	0.19	-1.93	0.054
Age Group 17-20mo by 22-25mo: Step 1	-0.23	0.20	-1.13	0.257
Age Group 17-20mo by 22-25mo: Step 2	0.37	0.20	1.80	0.073
Age Group 17-20mo by 22-25mo: Step 3	0.36	0.20	1.77	0.076
Age Group 22-25mo by 27-30mo: Step 1	0.22	0.21	1.06	0.289
Age Group 22-25mo by 27-30mo: Step 2	-0.82	0.20	-4.18	<0.001
Age Group 22-25mo by 27-30mo: Step 3	0.10	0.20	0.49	0.622
ot2: Age Group 12-15mo by 17-20mo: Step 1	0.61	0.20	3.04	<0.01
Age Group 12-15mo by 17-20mo: Step 2	-1.01	0.19	-5.18	<0.001
Age Group 12-15mo by 17-20mo: Step 3	-0.23	0.21	-1.13	0.259
Age Group 17-20mo by 22-25mo: Step 1	-0.02	0.21	-0.07	0.944
Age Group 17-20mo by 22-25mo: Step 2	-0.64	0.21	-2.98	<0.01
Age Group 17-20mo by 22-25mo: Step 3	1.03	0.21	4.80	<0.001
Age Group 22-25mo by 27-30mo: Step 1	-0.51	0.22	-2.36	<0.05
Age Group 22-25mo by 27-30mo: Step 2	0.82	0.21	3.96	<0.001
Age Group 22-25mo by 27-30mo: Step 3	-0.21	0.21	-1.00	0.316
First Look:Age Group 12-15mo by 17-20mo: Step 1	0.13	0.06	2.02	<0.05
Age Group 12-15mo by 17-20mo: Step 2	-0.23	0.06	-3.71	<0.001
Age Group 12-15mo by 17-20mo: Step 3	-0.02	0.06	-0.30	0.764
Age Group 17-20mo by 22-25mo Step 1	-0.21	0.07	-3.08	<0.01
Age Group 17-20mo by 22-25mo: Step 2	0.11	0.07	1.68	0.093
Age Group 17-20mo by 22-25mo: Step 3	0.04	0.07	0.64	0.520
Age Group 22-25mo by 27-30mo: Step 1	0.15	0.07	2.21	<0.05
Age Group 22-25mo by 27-30mo: Step 2	-0.01	0.07	-0.13	0.894
Age Group 22-25mo by 27-30mo: Step 3	-0.17	0.07	-2.50	<0.05
ot1: First Look: Age Group 12-15mo by 17-20mo: Step 1	1.42	0.39	3.69	<0.001
First Look: Age Group 12-15mo by 17-20mo: Step 2	-1.52	0.38	-3.99	<0.001
First Look: Age Group 12-15mo by 17-20mo: Step 3	0.84	0.40	2.11	<0.05
First Look: Age Group 17-20mo by 22-25mo: Step 1	0.50	0.42	1.19	0.235
First Look: Age Group 17-20mo by 22-25mo: Step 2	-0.01	0.42	-0.03	0.972
First Look: Age Group 17-20mo by 22-25mo Step 3	-0.59	0.41	-1.42	0.155
First Look: Age Group 22-25mo by 27-30mo: Step 1	-0.16	0.42	-0.39	0.698
First Look: Age Group 22-25mo by 27-30mo: Step 2	2.59	0.40	6.45	<0.001
First Look: Age Group 22-25mo by 27-30mo: Step 3	-1.01	0.41	-2.49	<0.05
ot2: First Look: Age Group 12-15mo by 17-20mo: Step 1	1.30	0.41	3.19	<0.01
First Look: Age Group 12-15mo by 17-20mo: Step 2	-1.74	0.40	-4.39	<0.001
First Look: Age Group 12-15mo by 17-20mo: Step 3	0.38	0.42	0.91	0.365

First Look: Age Group 17-20mo by 22-25mo: Step 1	-1.21	0.44	-2.78	<0.01
First Look: Age Group 17-20mo by 22-25mo: Step 2	0.78	0.44	1.79	0.074
First Look: Age Group 17-20mo by 22-25mo: Step 3	-0.32	0.43	-0.74	0.460
First Look: Age Group 22-25mo by 27-30mo: Step 1	-0.21	0.44	-0.48	0.631
First Look: Age Group 22-25mo by 27-30mo: Step 2	0.59	0.42	1.39	0.166
First Look: Age Group 22-25mo by 27-30mo: Step 3	-1.04	0.43	-2.42	<0.05

“ot” refers to the orthogonal time terms, such that ot1 refers to the linear term and ot2 the quadratic

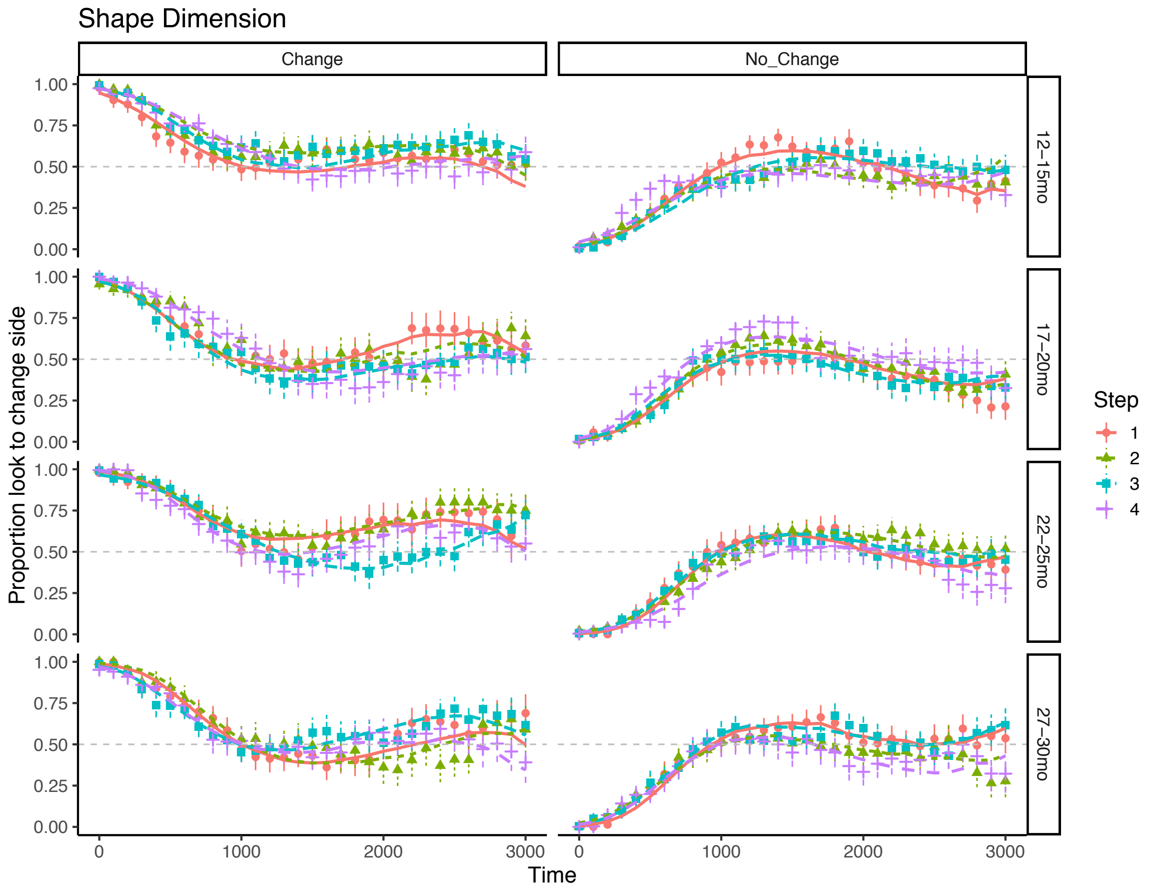

Figure 26. The time course of fixations for each of the Step changes (1,2,3,4) during the test array, separated by first look location (change side v. no change side) for all four age groups (12-15mo, 17-20mo, 22-25mo, 27-30mo). The dotted line indicates chance looking at 50%.

In the first set of results, colour unlike the other two dimensions (shape and orientation), did have a significant effect overall looking to the change side suggesting children were able to discriminate. The colour dimension time course data also differed from the shape and orientation dimensions, as it followed a curve with two peaks, as opposed to one peak. The time course data indicated that children shifted their looking more often, generating three shifts in looking over the 3000 ms trial. The modelling of the time course data reveals how looking changes for age group and step contributed to discrimination of the colour beasties, in addition to where infants were looking at the start of the trial.

The model coefficients reveal main effects of first look and step, but no main effect of age group. For first look, children who started the test array looking to the change side, had significantly more looking to the change side over the course of the trial compared to children who started the test array looking to the no change side. These children had a gradual decrease in their looking to the change side, as they switched from the change side to the no change side around 1400 ms, they then shifted their looking back to the change side were they continued to look until about 2500 ms, there was then a final shift to the no change side, which continued till the test array offset. The children who started the test array looking to the no change side showed the exact opposite pattern; a gradual shift to the change side till about 1400 ms, shift back to no change side around 2500 ms, and a final shift to the change side till the reminder of the test array.

The main effect of step revealed children had a significant increase in looking to the change side for a 45-degree change (step 3). For this step 3 change, participants significantly shifted their looking to the change side around 500 ms from the onset of the test array, indicating that participants were able to detect the 45-degree change in colour. The interaction between step and first look revealed a difference in discrimination depending on where participants were looking at the start of the test array. Children who started the test array looking to the change side had a significant shift in looking back to the change side for the smallest step change (15-degrees), whereas children who started the test looking to the no change side had a significant shift in looking to the change side for the largest step change (60-degrees). These results suggest that beginning the test array looking to the change side may help you to discriminate smaller degree changes, whereas starting the trial looking to the no change side participants require a larger degree change to discriminate the colour beasties.

The model coefficients found an interaction of first look and age group. This interaction suggests children who start the test array looking at the change side had quicker shifts in looking to the no change side and then back to the change side for the youngest age group (12-15mo). This effect may further support the idea that where children start the test array affects their looking trajectory over the time course. In particular, starting on the change side has been found to increase discrimination for smaller degree changes and four younger children.

As for age and step the model coefficients revealed several interactions. The 12-15-month-old children had more looking to the change side on a 15- degree step change compared to 17-20-month-old children over the trial time. However, 17-20-month-old had significantly more looking to the change side over the course of the trial for a 45-degree step change. It is interesting that 12-15-month-old are able to notice the change at a smaller step size compare to their older counter parts who need a larger step size to show a significant shift in looking to the change side. The 17-20-month-old children also has less looking on step 1 (15-degrees) compared to 22-25-month-old who showed pattern of increased looking to the change side for a 15-degree step change over the trial time. The last interaction between step and age group reveals that 22-25-month-old children have less looking to the change side over the course of the trial for a 30-degree change. The results for the age and step indicate that as children get older does not necessarily mean they are able to detect smaller step changes than their younger peers.

The model coefficients suggested that there were significant effects found within the three-way interaction between step, age group and first look. The 17-20-month-old children had a faster shift in their looking for 15-degree step change for those who started the trial looking on the change side, where as 17-20-month-old children had faster shift in their looking for a 60-degree change. This effect mirrored the interacted found between first look and step where starting the trial on the no change side had a faster shift change in looking to the change side for a 60-degree change. The next effect found that carried over the pattern of looking found for 17-20-month-olds showing that 22-25-month-olds had a slower rate of change in looking to the 60-degree change compared to 17-20-month-olds. Although 22-25-month-olds rate of looking to the 60-degree change was less than 17-20-month-olds, within this age group this 60-degree change had a faster rate of looking compare to the smallest step change of 15-degrees and compared to the oldest age group 27-30-month-olds. This suggest that they are able to discriminate the 60-degree colour change but shift their looking to the change side slower than 17-20-month-old children, but yet faster than 27-30-month-olds.

The three-way results show how children's looking over the course of the test array can shift depending on the size of the change and the age range of the participants. Some children are able to shift to the change side fairly quickly with a smaller step change, where as other need a larger step change to push there looking to the changed object. It is also interesting that some of the effect found in the two-interaction were also seen within the three-way interaction, specifically children who start the test array on the no change side had significant shifts to the change side when the step change was larger. It might be possible that the colour changes are easier for the children to notice as from the original overall looking analysis colour was the only dimension to have significantly more looking to the change side. Therefore, because this dimension was easier for children to discriminate it could be why we see children in the time course analysis significantly shift their looking to the change side despite starting the test array on the no change side.

Overall the colour dimension time course results reaffirmed children's ability to discriminate the colour changes in the beasties. As with the previous two dimensions, it was beneficial for children who started the trial looking to the change side, however for larger step changes children who started on the no change side were able to shift their looking suggesting they recognized the colour change. Similar to the shape and orientation findings children's looking varied by step and age group. The time course of their looking did not follow a singular pattern where older children discriminated or looked to the change side more. The age effect or lack thereof may suggest that there is no age difference between our groups and that 12-months to 30-months is not a large enough difference to see age effects.

Table 6. Time course analysis model coefficients for the Colour dimension

Fixed Effects Colour	*Estimates*	*SE*	*t*	*p*
First Look	1.10	0.02	48.04	<0.001
ot1: First Look	-8.60	0.17	-50.08	<0.001
ot2: First Look	9.13	0.16	58.12	<0.001
ot3: First Look	-7.50	0.16	-46.98	<0.001
Step:1 by 2	0.02	0.02	1.22	0.221
2 by 3	-0.09	0.02	-4.47	<0.001
3 by 4	0.00003	0.02	0.002	0.999
ot1: 1 by 2	-0.12	0.14	-0.85	0.393
2 by 3	-0.80	0.14	5.58	<0.001
3 by 4	-0.67	0.14	-4.76	<0.001
ot2: 1 by 2	-0.20	0.13	-1.47	0.141
2 by 3	0.30	0.13	2.31	<0.05
3 by 4	0.29	0.13	2.27	<0.05
ot3: 1 by 2	-0.72	0.13	-5.36	<0.001
2 by 3	0.05	0.13	0.39	0.698
3 by 4	0.32	0.13	2.38	<0.05
Age Group:12-15mo by 17-20mo	-0.03	0.04	-0.60	0.547
17-20mo by 22-25mo	0.06	0.05	1.37	0.173
22-25mo by 27-30mo	-0.04	0.05	-0.82	0.414
ot1: 12-15mo by 17-20mo	-0.23	0.31	-0.74	0.462
17-20mo by 22-25mo	0.70	0.33	2.13	<0.05
22-25mo by 27-30mo	0.05	0.33	0.15	0.882
ot2: 12-15mo by 17-20mo	0.20	0.30	0.64	0.523
17-20mo by 22-25mo	-0.01	0.31	-0.04	0.966
22-25mo by 27-30mo	0.21	0.32	0.65	0.516
ot3: 12-15mo by 17-20mo	-0.31	0.26	-1.18	0.236
17-20mo by 22-25mo	0.69	0.30	2.49	<0.05
22-25mo by 27-30mo	-0.05	0.30	-0.19	0.852
First Look: Step: 1 by 2	0.19	0.04	4.88	<0.001
First Look: 2 by 3	0.06	0.04	1.53	0.126
First Look: 3 by 4	-0.11	0.04	-2.94	<0.01
ot1: First Look: 1 by 2	-0.32	0.29	-1.09	0.277
First Look: 2 by 3	-0.27	0.29	-0.92	0.359
First Look: 3 by 4	-0.54	0.29	-1.88	0.060
ot2: First Look: 1 by 2	0.65	0.27	2.40	<0.05
First Look: 2 by 3	0.72	0.27	2.68	<0.01
First Look: 3 by 4	-0.21	0.26	-0.80	0.0424
ot3: First Look: 1 by 2	0.58	0.27	2.14	<0.05
First Look: 2 by 3	1.25	0.27	4.60	<0.001
First Look: 3 by 4	-0.34	0.27	-1.26	0.208

First Look: Age Group:12-15mo by17-20mo	0.14	0.04	3.70	<0.001
17-20mo by 22-25mo	-0.06	0.04	-1.61	0.109
22-25mo by 27-30mo	0.08	0.04	1.93	0.054
ot1: 12-15mo by 17-20mo	-0.26	0.28	-0.94	0.349
17-20mo by 22-25mo	0.18	0.29	0.62	0.535
22-25mo by 27-30mo	0.40	0.31	1.29	0.196
ot2: 12-15mo by 17-20mo	-0.50	0.26	-1.95	0.052
17-20mo by 22-25mo	0.13	0.27	0.49	0.636
22-25mo by 27-30mo	0.83	0.28	2.84	<0.01
ot3: 12-15mo by 17-20mo	1.31	0.26	5.05	<0.001
17-20mo by 22-25mo	-0.8	0.27	-0.30	0.761
22-25mo by 27-30mo	-0.69	0.28	-2.42	<0.05
Age Group 12-15mo by 17-20mo: Step 1	0.12	0.03	3.77	<0.001
Age Group 12-15mo by 17-20mo: Step 2	-0.08	0.03	-2.44	<0.05
Age Group 12-15mo by 17-20mo: Step 3	-0.04	0.03	-1.25	0.212
Age Group 17-20mo by 22-25mo: Step 1	-0.07	0.03	-2.16	0.031
Age Group 17-20mo by 22-25mo: Step 2	-0.02	0.03	-0.55	0.585
Age Group 17-20mo by 22-25mo: Step 3	0.06	0.03	1.90	0.058
Age Group 22-25mo by 27-30mo: Step 1	-0.09	0.04	-2.40	0.016
Age Group 22-25mo by 27-30mo: Step 2	-0.07	0.03	-2.20	0.028
Age Group 22-25mo by 27-30mo: Step 3	-0.04	0.03	-1.09	0.0275
ot1: Age Group 12-15mo by 17-20mo: Step 1	-1.10	0.23	-4.75	<0.001
Age Group 12-15mo by 17-20mo: Step 2	0.06	0.24	0.27	0.787
Age Group 12-15mo by 17-20mo: Step 3	0.41	0.22	1.85	0.065
Age Group 17-20mo by 22-25mo: Step 1	0.63	0.24	2.63	<0.01
Age Group 17-20mo by 22-25mo: Step 2	-1.18	0.25	-4.77	<0.001
Age Group 17-20mo by 22-25mo: Step 3	0.55	0.24	2.27	<0.05
Age Group 22-25mo by 27-30mo: Step 1	0.88	0.28	3.20	<0.01
Age Group 22-25mo by 27-30mo: Step 2	0.47	0.25	1.88	0.061
Age Group 22-25mo by 27-30mo: Step 3	-0.69	0.24	-2.86	<0.01
ot2: Age Group 12-15mo by 17-20mo: Step 1	1.48	0.21	6.93	<0.001
Age Group 12-15mo by 17-20mo: Step 2	-1.45	0.22	-6.68	<0.001
Age Group 12-15mo by 17-20mo: Step 3	-0.29	0.21	-1.39	0.163
Age Group 17-20mo by 22-25mo: Step 1	0.09	0.22	0.42	0.673
Age Group 17-20mo by 22-25mo: Step 2	0.43	0.23	1.91	0.056
Age Group 17-20mo by 22-25mo: Step 3	-0.36	0.23	-1.61	0.107
Age Group 22-25mo by 27-30mo: Step 1	-1.68	0.25	-6.72	<0.001
Age Group 22-25mo by 27-30mo: Step 2	0.89	0.23	3.88	<0.001
Age Group 22-25mo by 27-30mo: Step 3	-0.22	0.22	-0.99	0.320
ot3: Age Group 12-15mo by 17-20mo: Step 1	-0.79	0.22	-3.67	<0.001
Age Group 12-15mo by 17-20mo: Step 2	0.50	0.22	2.26	<0.05
Age Group 12-15mo by 17-20mo: Step 3	0.07	0.21	0.35	0.729
Age Group 17-20mo by 22-25mo: Step 1	-0.28	0.23	-1.24	0.217
Age Group 17-20mo by 22-25mo: Step 2	-0.28	0.23	-1.21	0.228
Age Group 17-20mo by 22-25mo: Step 3	0.41	0.23	1.74	0.082
Age Group 22-25mo by 27-30mo: Step 1	0.97	0.25	3.92	<0.001
Age Group 22-25mo by 27-30mo: Step 2	-0.01	0.24	-0.03	0.977
Age Group 22-25mo by 27-30mo: Step 3	-0.32	0.23	-1.38	0.167
First Look:Age Group 12-15mo by 17-20mo: Step 1	-0.26	0.06	-4.05	<0.001
Age Group 12-15mo by 17-20mo: Step 2	0.05	0.07	0.79	0.430
Age Group 12-15mo by 17-20mo: Step 3	0.12	0.06	1.85	0.064
Age Group 17-20mo by 22-25mo Step 1	0.11	0.07	1.61	0.107
Age Group 17-20mo by 22-25mo: Step 2	-0.02	0.07	-0.23	0.816
Age Group 17-20mo by 22-25mo: Step 3	-0.27	0.07	-4.02	<0.001
Age Group 22-25mo by 27-30mo: Step 1	0.12	0.07	1.59	0.112
Age Group 22-25mo by 27-30mo: Step 2	-0.09	0.07	-1.28	0.201
Age Group 22-25mo by 27-30mo: Step 3	0.18	0.07	2.64	<0.01
ot1: First Look: Age Group 12-15mo by 17-20mo: Step 1	0.09	0.50	0.19	0.853
First Look: Age Group 12-15mo by 17-20mo: Step 2	-0.22	0.50	-0.45	0.652
First Look: Age Group 12-15mo by 17-20mo: Step 3	0.73	0.45	1.60	0.109
First Look: Age Group 17-20mo by 22-25mo: Step 1	2.75	0.50	5.63	<0.001
First Look: Age Group 17-20mo by 22-25mo: Step 2	-2.58	0.51	-5.08	<0.001
First Look: Age Group 17-20mo by 22-25mo Step 3	0.16	0.50	0.32	0.747
First Look: Age Group 22-25mo by 27-30mo: Step 1	-4.38	0.55	-7.85	<0.001
First Look: Age Group 22-25mo by 27-30mo: Step 2	1.57	0.51	3.09	<0.01
First Look: Age Group 22-25mo by 27-30mo: Step 3	2.53	0.49	5.12	<0.001
ot2: First Look: Age Group 12-15mo by 17-20mo: Step 1	-1.62	0.43	-3.74	<0.001
First Look: Age Group 12-15mo by 17-20mo: Step 2	0.47	0.44	1.05	0.292
First Look: Age Group 12-15mo by 17-20mo: Step 3	-0.85	0.42	-2.02	0.043
First Look: Age Group 17-20mo by 22-25mo: Step 1	-0.47	0.45	-1.04	0.298
First Look: Age Group 17-20mo by 22-25mo: Step 2	-1.56	0.46	-3.37	<0.001
First Look: Age Group 17-20mo by 22-25mo: Step 3	0.91	0.46	1.98	<0.05
First Look: Age Group 22-25mo by 27-30mo: Step 1	3.36	0.51	6.64	<0.001
First Look: Age Group 22-25mo by 27-30mo: Step 2	-0.04	0.47	-0.09	0.927
First Look: Age Group 22-25mo by 27-30mo: Step 3	-0.97	0.46	-2.11	<0.05

ot3: First Look: Age Group 12-15mo by 17-20mo: Step 1	1.22	0.44	2.80	<0.01
First Look: Age Group 12-15mo by 17-20mo: Step 2	-0.95	0.45	-2.12	<0.05
First Look: Age Group 12-15mo by 17-20mo: Step 3	0.68	0.43	1.58	0.113
First Look: Age Group 17-20mo by 22-25mo: Step 1	0.22	0.46	0.47	0.638
First Look: Age Group 17-20mo by 22-25mo: Step 2	1.07	0.47	2.27	0.023
First Look: Age Group 17-20mo by 22-25mo: Step 3	-0.68	0.48	-1.44	0.151
First Look: Age Group 22-25mo by 27-30mo: Step 1	-1.86	0.50	-3.74	<0.001
First Look: Age Group 22-25mo by 27-30mo: Step 2	-0.48	0.48	-1.00	0.320
First Look: Age Group 22-25mo by 27-30mo: Step 3	0.84	0.47	1.80	0.072

"ot" refers to the orthogonal time terms, such that ot1 refers to the linear term and ot2 the quadratic

3.3.5 Discussion 2

The time course data provided a more detailed picture of how children's looking changed over the course of the test array compared to the results from overall looking times to the change and no change side. As suspected, not having a fixation stimulus did result in some infants looking to the change side, and others to the no change side when the test array appeared. The time course data did reveal that children's looking behaviour oscillates back and forth between the change and no change side over the time course of the test array regardless of where the infants looking began. Despite the fact that looking does oscillate, the time course models' results suggest significantly more looking to the change side for all three dimensions indicating that children were able to detect changes in the shape, orientation, and colour, of the beasties contrary to the overall looking results found in Experiment 3a. Through the analysis of the time course data, we found that where children are looking at the start of the test array influences their looking to the change and no change side throughout the test array trial. In particular, children that started on the change side tend to have more time to looking to the change side compared to children who started on the no change side. The effect of this first look was further mediated by the age of the children and the degree of change found in the separate analysis of the dimensions.

The shape dimension model suggested that participants were able to detect the change in the beastie at a 30-degree change (step 2) and that 22-25-month-old children were better able to detect the shape changes compared to 27-30-month-old children. The orientation model also found that children were able to detect the change in the beastie at an 18-degree change (step 2) but found no effect of age. The colour model suggested that participants required a larger degree of change, 45-degrees (step 3), to detect the change than shape and orientation models. The colour model also suggests no effect of age. Although first look, step, and age interacted together to find that younger and older ages able to detect differing degrees of change, these effects did not follow a pattern indicative of age growth suggesting the older age group did not out preform the younger age groups.

The results from the time course analysis with the addition of the variable first look, revealed some interesting dynamics of children's looking in the discrimination task that was missed in the first set of analyses. These results provided a clearer and more detailed picture of what children were doing moment to moment and how their looking shifted over time, between dimension, step, and age. However, a central goal of these experiments was to identify whether the beastie objects were distinct enough for children to tell apart, especially for children age 12-14-months and for beasties that changed in colour and shape at 60-degree change. The major concern with using these stimuli was that the beasties were not generating similar attention and looking times as the Smith and Yu stimuli. Taken together the child discrimination data from both analyses suggest that the beasties are not highly discriminable objects. Although we had some promising results suggesting that children from 12-30-months on average had more looking and had significant shifts to the change side indicating some levels of discrimination, the results were neither uniform nor systematic across age and step. As for dimension, children were able to detect changes in colour, but orientation and shape results suggested lesser discrimination. Therefore, while these results lead some support that the beastie objects are somewhat discriminable, the objects used for the cross situational experiments with children between 12-14-month-of-age may be too similar overall and insufficient to generate the looking needed for word learning.

Chapter 4: Visual dynamics of cross situational word learning, Exact replication of Smith and & Yu, 2008

4.1 Experiment 4

Although adults could clearly discriminate the beasties, children had a harder time doing so. Analysis of children's looking over the time course of the discrimination trials provides some indication that children do perceive the differences in the beasties. Nevertheless, for our final attempt to replicate the cross situational word learning findings we contacted Linda Smith and Chen Yu and asked to have a video copy of their stimuli. In Experiment 4, we used the video they sent us to conduct an exact replication of Smith and Yu (2008) and Yu and Smith (2011) with the additional use of an eye tracker.

4.1.1 Methods

4.1.1.1 Participants

Twenty-two 12-month-old infants (14 males, 8 females) and 30 14-month-old infants (14 males, 17 females) were recruited from a Southeast college town via community outreach and a lab registry. All infants were from middle class working families that spoke English more than 50% of the time. In our study 40 children began the experiment but did not finish due to fussiness (23) or equipment failure (13), parental interference (2), and recruitment error (2). An additional 8 infants completed the study but did not contribute data because either their average looking during the training trials was more than 2 standard deviations below the overall mean (3), or they demonstrated a bias to look to the right or left that was +/- 2 standard deviations of the total average looking to the right or left (5). The fact that our drop rate was still relatively very high, especially in terms of the number of infants fussing out suggest that while our beastie stimuli may not be highly discriminable, the task itself may be the issue here. Likewise, the number of drops due to low looking rates or biases is also indicative of general task difficulties. Lastly, although some of the drops can be attributed to testing failure, Experiment 4 had the highest drop rate and was conducted with the use of Smith and Yu stimuli.

4.1.1.2 Stimuli

The six novel words used were identical to experiments 1 and 2. The six novel objects, however, were replaced with those used in Smith and Yu's study (2008) and Yu and Smith (2011). These objects were drawings of novel shapes, each with a unique and bright colour (see Figure 27). The stimuli were presented on a 42 -inch monitor with a white background. The words were presented over the monitor's loudspeaker. The stimuli were between 8 to 10 inches in projected size, separated on the screen by 15 inches, and had an average visual angle of 16 degrees.

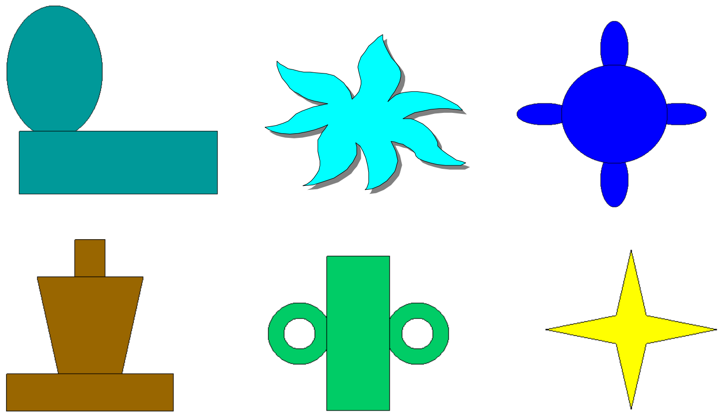

Figure 27. The six novel objects used in Experiment 3.

4.1.1.3 Procedure

A Dell computer running Experiment Builder (SR- Research, Ontario, Canada) presented the experiment on a 42-inch monitor at a distance of 100 centimetres. An EyeLink 1000 plus remote tracker was used. The eye tracking camera was located at the base of the monitor on a small stand at a distance between 600 to 700 centimetres. The eye tracker had a monocular focus affixed to the right eye and tracked gaze position using pupil and corneal reflections of an infrared light source. Eye position was maintained using a target sticker, allowing the eye tracker to relocate the eye as the participant moved. The tracker's sampling rate was 500 Hz. There were two additional cameras, one located at the bottom of the monitor to record the participant's face, and one located at the back of the room to record the experiment as it was presented on the monitor.

Infants were seated on their caregivers' lap 42 inches from the screen. Caregivers wore blackout sunglasses, which obscured their vision throughout the entire procedure, and were asked to refrain from pointing to or otherwise or drawing their child's attention to the screen. The experiment began with a short video of *Elmo's World.* During this video, the experimenter placed the tracking sticker on the participants' forehead. Once the sticker was in position the calibration procedure began. Participants were shown a looming black and white geometric object at five points of the screen (middle, top, bottom, right, left) to map raw eye position data to the camera image data and thereby map gaze position to the stimulus presentation. Following successful calibration, the experiment started.

The structure and duration of training and test trials was the same as Smith and Yu, 2008 and Yu and Smith, 2011. There were thirty training slides. Each slide presented two of the novel objects for four seconds. The first word was presented 500 ms after the onset of the slide. The second word was presented 500 ms after the end of the first word. All six words were 1000 ms in length. Over the course of the 30 training slides, each of the six word-object pairs occurred 10 times. Each word-object pair co-occurred with every other word-object pair five times in the training trials. During training trials an attention grabber (picture of a Sesame Street character) appeared in the centre of the screen for four seconds* before the start of the first training slide and every three slides thereafter to maintain attention.

Training was followed by 12 test slides, which were presented for 8000 ms each. On each test trial two objects were presented on the screen, but unlike training, only one word, repeated four times, was presented. The first spoken iteration of the word occurred at 500 ms, the second at 2000 ms, the third at 4500 ms, and the fourth at 6000 ms. The object with which this word had co-occurred during training was designated as the target. The other object served as the distractor. Each of the six words were presented twice.

There were two sets of experimental slides with different presentation orders and different word-object pairs. The first set was identical to order in the video from Smith and Yu. This second order was organized according to Smith and Yu's (2008) procedure, with the right and left position of the objects, order of names, with the target word and location of the objects selected randomly such that each object appeared equally often on both sides and each word was stated first and second equally often.

An attention grabber (picture of a Sesame Street character) appeared in the centre of the screen for four seconds* and was repeated three times before the start of the first training slide. It then was repeated every slide for the first four training slides. The attention getter then appeared every three slides in training thereafter to maintain attention. For test, attention getters appeared every other slide until the completion of the study.

* It should be noted that Smith and Yu (2008) report the length of the attention getter video as three seconds, however upon review of the video we found the length to be four seconds. Therefore, we extend the length of the attention getter to replicate that of the video received from Smith and Yu (2008). Also see Table 8 in the appendix for a direct comparison of the experiment details.

4.1.1.4 Data Analysis

Raw eye position data from the eye tracker was broken down into events such as fixations, saccades, and blinks using Data Viewer (SR- Research, Ontario, Canada). For analysis, trials were segmented from attention getters that were defined by message-based training trials and test trials start and end times. Similar to Yu and Smith (2011), areas of interest (AOIs) were created by splitting the screen into left and right sides, which contained each object. These large interest areas accounted for calibration error and drift in the eye tracker. Interest area reports for the training and test trials provided dwell time and number of fixations for each AOI, switches between AOIs and average pupil dilation.

4.1.2 Results 1

To examine our direct replication of Smith and Yu (2008) and Yu and Smith (2011), we first compare the descriptive data from training and test trials to Smith and Yu (2008) and Yu and Smith (2011). We then look at overall learning, and finally, individual looking dynamics on training and test.

Training Trials

On average, infants looked at the right and left sides of each training slide for equal durations. Preliminary data analysis indicated average total looking for all 4000 ms training trials was 3010 ms for 12-month-olds and 3074 ms for 14-month-olds. Infants spent at least 1 second looking at each object on a training slide on 41% of the trials for 12-month-olds and 50% for 14-month-olds. Twelve -month-old infants spent at least 500 ms looking at each object on 68% of the training trials and 75% for 14-month-old infants. Our results are similar to that of Smith and Yu's (2008) average of 3040 ms on training trials, however our percentage of infants who spent at least 500 ms looking at each object is still low compared to their 87%.

Test Trials

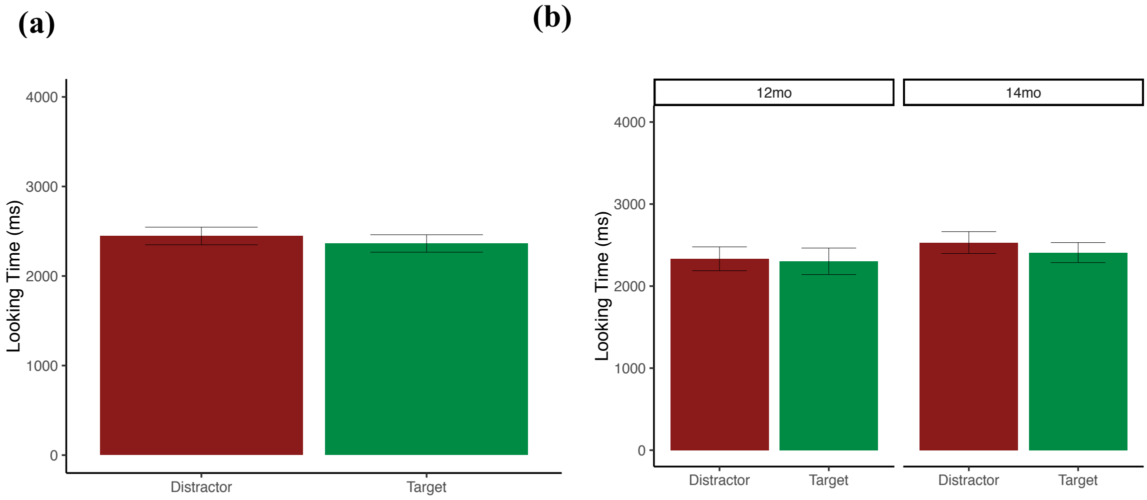

Figure 28. Mean looking time to distractor and target per 8000 ms test trial (and standard error of the mean). (a) 12 and 14-month-old data combined, (b) data for 12- and 14-month-olds separated.

On average, infants looked at each 8-second test slide for a total of 4635 ms for 12-month-olds and 4939 ms for 14-month-olds. Overall, infants did not look more to the target (2363 ms) than the distractor (2447 ms), $t(51)=0.89$, $p=0.379$ (Figure 28). When separated, 12-month-olds did not show a greater difference in looking time to the target (2302 ms) than the distractor (2333 ms), $t(21)=0.206$, $p=0.838$. Likewise, the 14-month-olds did not show a greater looking to the target (2408 ms) than the distractor (2531 ms), $t(29)=0.998$, $p=0.326$, as can be seen in Figure 28.

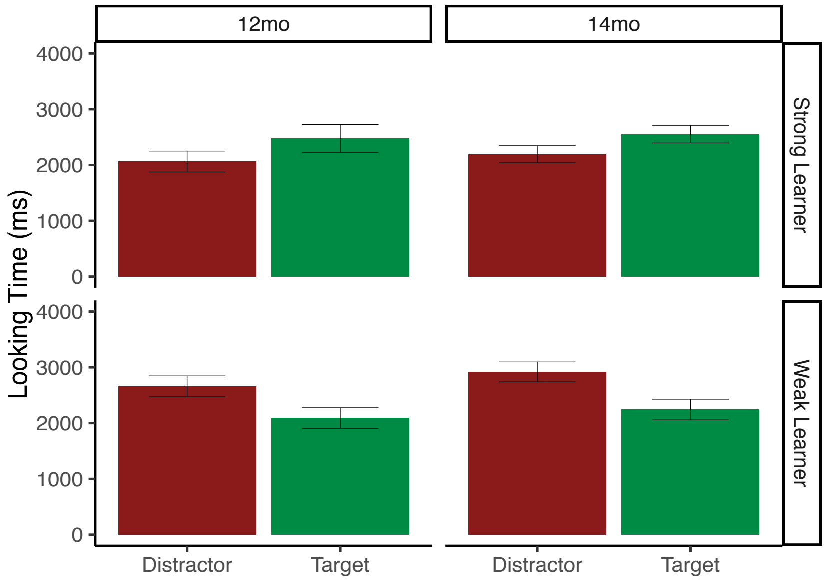

Figure 29. Mean looking time to distractor and target per 7000 ms test trial for 12- and 14-month-old strong and weak learners (and standard error of the mean).

We again separated the participants into strong and weak learners to investigate their looking dynamics. There were 12 12-month-old strong word learners and 10 weak word learners. The 12-month-old strong learners learned an average of 3.85 words, whereas the weak learners learned 1.99 words. The strong learners had significantly more looking to the target (2478 ms) than the distractor (2062 ms), $t(11)=-2.96$, $p<0.05$, with the weak learners having significantly more looking to the distractor than the target (2660 ms v 2092 ms for distractor and target respectively), $t(9)= 3.34$, $p<0.01$. There were 16 strong 14-month-old word learners and 14 weak word learners. The 14-month-old strong learners learned an average of 3.50 words; the weak word learners learned 2.05 words. Strong learners had significantly more looking to the target (2553.02 ms) than the distractor (2192.30 ms), $t(15)=-3.98$, $p<0.001$, and the weak learners had significantly more looking to the distractor (2917 ms) than the target (2243), $t(13)= 5.17$, $p<0.001$.

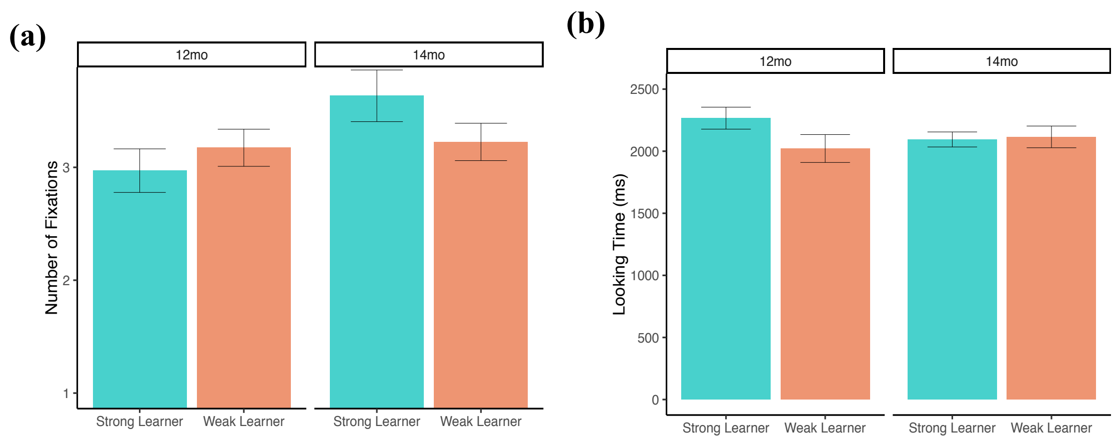

Figure 30. Training trial looking dynamics of training: (a) Mean count of fixations for strong and weak learners per 4000 ms training trial (and standard error of the mean). (b) Mean length of longest fixation for strong and weak learners per 4000 ms training trial (and standard error of the mean)

The average training trial looking time for 12-month-old strong learners (1751 ms) and weak learners (1582 ms) did not differ significantly, $t(18.04)=1.52$, $p=0.147$. Likewise, average training trial looking time for the 14-month-old strong learners (1629 ms) and weak learners (1641 ms) also did not differ significantly, $t(24.78)=-0.143$, $p=0.887$. There was also no significant difference for either age group with regards to max fixation length. The 12-month-old strong learners averaged of 2266 ms and the weak learners averaged 2022 ms $t(17.96)=1.71$, $p=.1045$. The 14-month-old strong learners (2095 ms) had similar max fixation length as the weak learners (2115 ms), $t(23.72)=-0.193$, $p=0.848$. The 12-month-old strong learners did have fewer fixations ($M=2.97$) than the weak learners ($M= 3.17$), $t(19.93)=-0.799$, $p=0.434$**.** Whereas, the 14-month-old strong learners had more fixations ($M= 3.63$) than the weak learners ($M=3.23$), although not significantly more, $t(26.44)=1.45$, $p=0.160$.

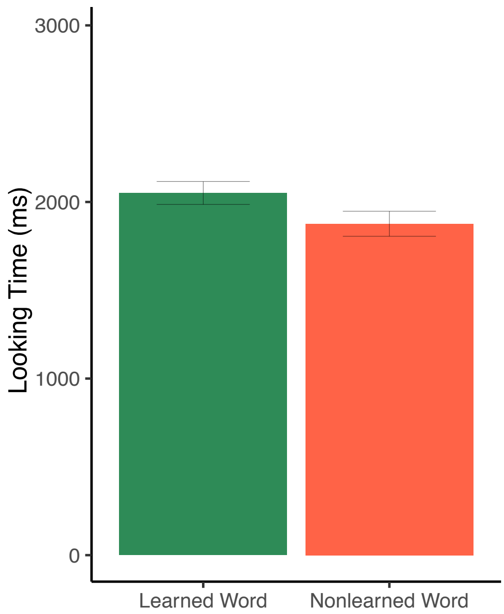

Figure 31. Mean looking to the correct object per 4s training trials for learned and non-learned words (and standard error of the mean).

Lastly, we investigated looking differences to learned and non-learned words over training. Overall, there was no significant difference in looking between the learned (*M*=2051 ms) and non-learned (1877 ms) words, t(51)=1.67, *p*=0.10. The final model included fixed effects for word type (learned/non-learned), trial block, and learner type (strong/weak) with an interaction between word type and learner type and random effects for subject. Age group was removed from the model as log likelihood tests found it was not a significant contributor to the model. There was a significant effect of trial block such that there was more looking on the first ten trials (1-10) than the middle ten trials (11-20), *t*(260)=2.24, *p*<0.05 and more looking on the middle ten trials than the last ten trials (21-30), *t*(260)=2.37, *p*<0.05 indicating habituation. There was also a main effect of word type, with more looking to learned words than non-learned words, *t*(260)=2.47, *p*<0.05. Lastly, there was a significant two-way interaction between learner type and word type, where strong learners had significantly more looking to the learned words than the non-learned words compared to weak learners, *t*(260)=7.55, *p*<0.001, however the lack of interaction with trial block suggests that this difference was evident from the beginning of the study.

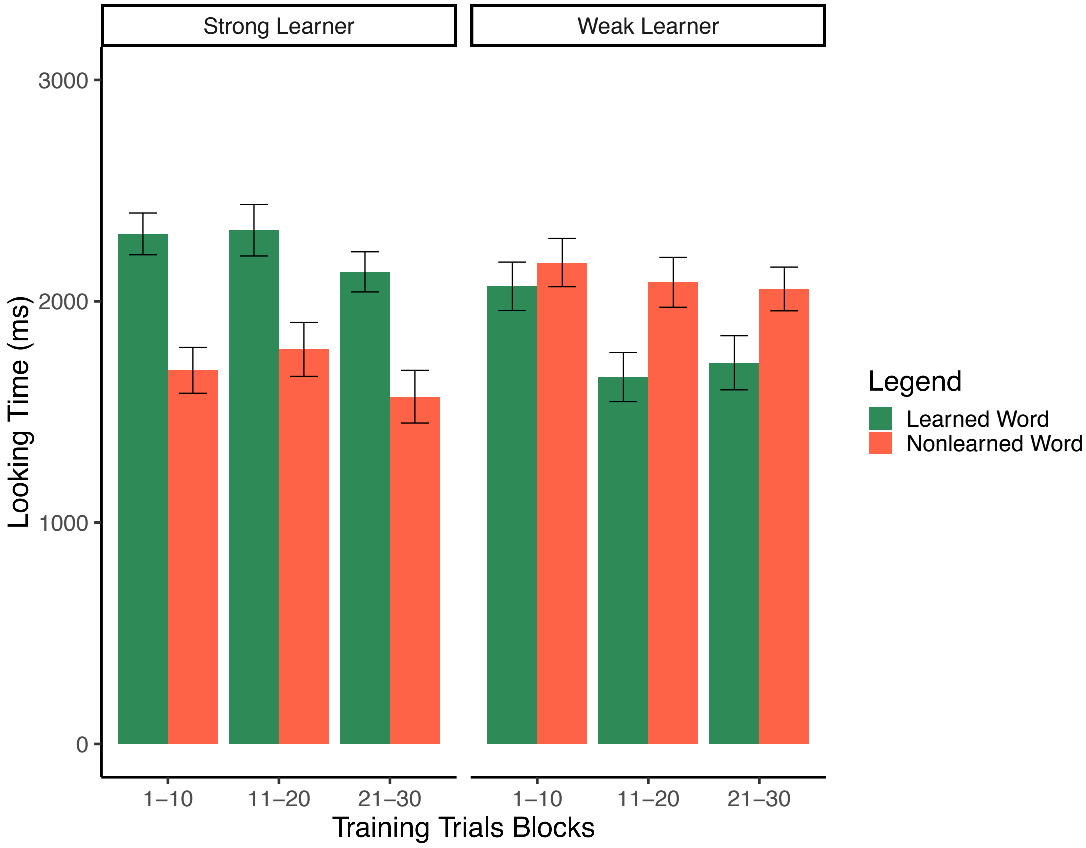

Figure 32. Mean looking to learned and non-learned words (and standard error of the mean) per 4 s training trial (and standard error of the mean).

4.1.3 Discussion

Similar to Experiment 2, we did not find evidence of word learning even when using Smith and Yu's stimuli. In addition, we did not find differences in the looking dynamics of the strong and weak learners. This study used the exact same stimuli, procedure, and even added an eye tracker to accurately measure infants' looking behaviour, as in Yu & Smith (2011). Our hope was that the amount of looking time infants demonstrated in this study would be similar to the amounts of overall looking Smith and Yu found previously, and that this would lead to stronger word learning. However, Experiment 3 had the least amount of looking during training: *M*= 3315 ms, 3196 ms and 3048 ms, for Experiments 1, 2 and 3 respectively, and significantly less than Experiment 1 (see Figure 33), $t(66)=3.28$, $p<0.01$ and also the highest drop rate. Thus, the changes in procedure and the new stimuli did not increase looking and possibly lead to lower levels of looking. In addition, as both Experiments 1 & 2 had higher levels of look than Experiment 4, suggesting that our stimuli were not the cause of lower looking levels.

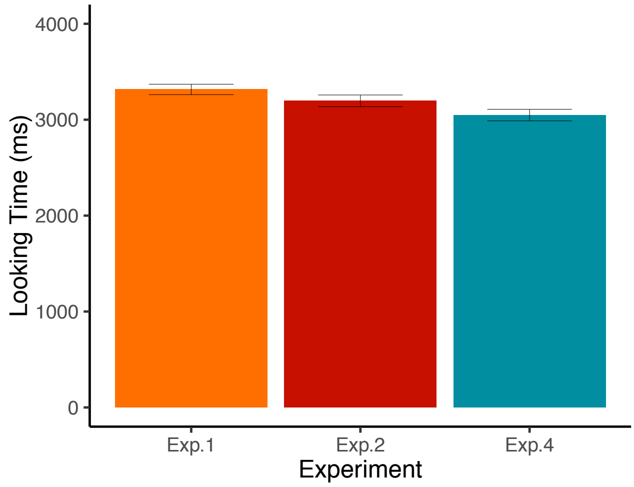

Figure 33. Average looking time across all three experiments.

As for the looking dynamics between the strong and weak learners, we once again failed to replicate the looking dynamics in Yu and Smith (2011). There was no significant difference in max fixation length, nor number of fixations on training trials for strong and weak learners in both the 12- and 14-month-old age groups. While the 12-month-olds trended toward similar looking dynamics as the children in Yu and Smith, with strong learners having fewer fixations with longer fixation lengths, the 14-month-old age group did not show similar trends. These results, taken together with those of Experiments 1 and 2, suggest that these looking dynamics, such as max fixation length and number of fixations during training are not a clear predictor of learning at test. In contrast, we did find a consistent pattern of looking to the objects associated with learned versus non-learned words for strong and weak learners across Experiments 1, 2, and 4. From the beginning of training, strong learners look more to objects that match words they evidence learning of at test while weak learners look more to objects that match the words they do not evidence having learned, and both groups show significant habituation. As we argued prior in chapter 2, this pattern suggests children's learning of words may be related to how they preferentially look and attend to objects, which is possibly shaped by familiarity and novelty preference, as well as what objects they look to when the study starts.

Experiment 4, as well as the prior cross situational experiments, were designed to replicate cross situational word learning in 12-and 14-month-olds. Once replicated, we planned to find what looking patterns led to successful cross situational word learning and develop ways to manipulate children's looking to increase word learning. However, we found that regardless of the age group, test trial length, or stimuli used, children as a group did not show evidence of reliable, above-chance looking to the target object at test. In addition, we found that children's word learning in the task may be related to looking driven by preferences for particular objects over others as indicated by learned and non-learned word-object looking dynamics. Yet before we completely close the book on learning words in the cross situational paradigm, we decided to examine at the time course data in Eyetracking R. Past research has noted gaze data (time course data) is a rich source for developmental research and it accounts for the complex moment to moment eye movements (Yu, Yurovsky, Xu, 2012). In our own time course analysis of the beasties stimuli in Experiment 3, we were able to see attentional shifts that provided additional information as to infants looking dynamics.

4.1.4 Data Analysis 2

Time course data was extracted out of Dataviewer. Data was then analysed in the R package Eyetracking R and through the use of logistic mixed effects models with R package glmmPQL. The following analysis examines infants' test trial looking through proportions of looking to the target object divided by the total proportion of looking to both the target and distractor objects. Data was cleaned in that trials where participants did not fixate on the screen for more that 70% of the test trial duration were removed to reduce noise within the data set (removing 224 trials). The model included random effects for subject with fixed effects for age group. In addition, we created a new variable called first look, which is the location of the eyes at the start of the test array (target /distractor), which was included as a fixed effect, as we did for the time course analysis in the discrimination studies. We believe that their pattern of looking over the course of the trial will be different depending on where they were looking at the start of the test trial. If they have learned the word-object mappings, infants who start the trial looking to the distractor object should switch to look to the target once they hear the target word, whereas infants who are already looking to the target object should maintain looking to that object. All fixed factors were effects coded and fitted with an optimal random effects structure.

The data follow a curved trend with three peaks; therefore, the time course data was modelled using forth order (quartic) orthogonal polynomials. The model examines children's gaze data over time (linear), $time^2$(quadratic), $time^3$ (cubic), and $time^4$(quartic) while examining the effects of age group and first look location on patterns of fixation.

4.1.4 Results 2

The results from the model (Table 7) indicate that there was a significant effect of first look location for the target object and an interaction with the linear, quadratic, cubic, and quartic polynomial terms. These results suggest overall proportion looking to the target and the overall time course of their looking during the trial is mediated by where infants begin looking on the test array. Participants who looked first to the distractor, do not look to the target at levels greater than chance, but do show some segments of significant looking to the distractor around the time of the second, third, and fourth word presentations (2000, 4500, and 6000 ms). However, participants who looked first to the target object maintain looking to that object at greater than chance levels throughout the 8s test trials. Further, these participants show increases in the proportion looking to the target around the second, third- and fourth-word presentations (2000, 4500 and 6000 ms) word onset, and at the end of the trial (Figure 34).

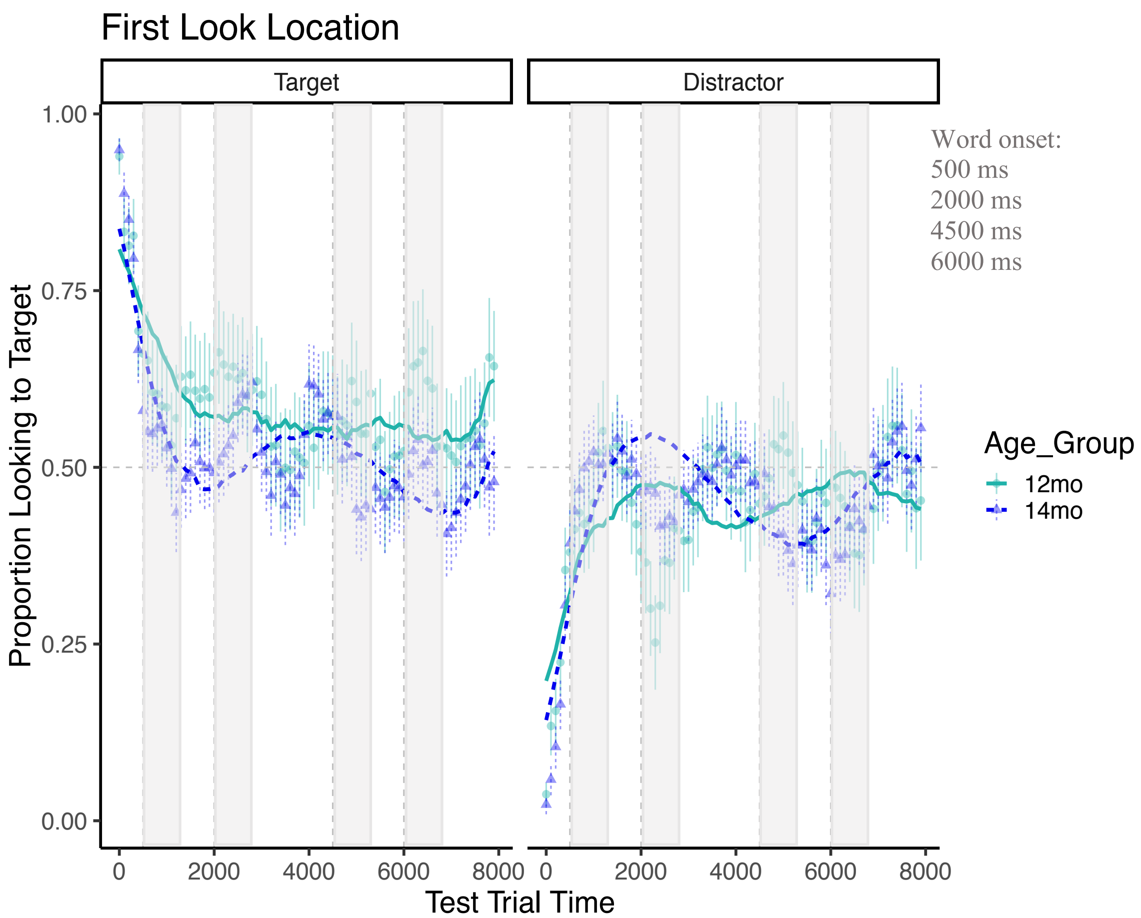

Figure 34. Looking proportions to the target object over the test trial time for age group.

Although there was no main effect of age group nor an interaction with any of the orthogonal terms, there was an interaction of age group and first look location that also interacted with the cubic and quartic polynomial terms. This suggests that there were significantly more 12-month-old participants who started their first look towards the target object. In addition, 12-month-olds who looked first to the target showed a significantly higher proportion of looks to the target in the later segments of the trial. Overall these results suggest that children who start the test trial looking to the target object maintained a higher proportion of looking to the target object throughout the trial despite the cyclical (back and forth) nature of their looking. Twelve-month-olds who started the test trial looking to the target object maintained a higher proportion of looking to the target object compared to 14-month-olds who also started the trial looking to the target object and 12-month-olds who started the test trial looking to the distractor object. Although these results would suggest that 12-month-olds demonstrated more word learning than the 14-month-olds, the 14-month-olds who started the test trial looking to the distractor object had a significant shift in looking to the target object, where 12-month-olds only had minor shifts in looking regardless of their first look location. The results suggest that 12-month olds have more sticky attention and maintain their looking over the time course, whereas 14-month-olds shift their looking more to the target and distractor objects, possibly indicating there is more driving their attention than stickiness.

Table 7. Time course analysis model coefficients

Fixed Effects	*Estimate*	*SE*	*t value*	*pr(>|t|)*
First Look: Target- Distractor	0.25	0.02	15.98	<0.001
ot1: First Look: Target- Distractor	-1.56	0.14	-10.81	<0.001
ot2: First Look: Target- Distractor	1.37	0.14	9.42	<0.001
ot3: First Look: Target- Distractor	-1.63	0.15	-11.24	<0.001
ot4: First Look: Target- Distractor	1.15	0.14	8.03	<0.001
Age Group: 12mo-14mo	0.11	0.07	1.56	0.126
ot1: Age Group 12mo-14mo	-0.16	0.56	-0.29	0.769
ot2: Age Group: 12mo-14mo	0.02	0.52	0.04	0.968
ot3: Age Group: 12mo-14mo	-0.77	0.59	-1.31	0.190
ot4: Age Group: 12mo-14mo	-0.59	0.52	-1.13	0.260
First Look: Age Group	0.06	0.02	3.71	<0.001
ot1: First Look: Age Group	-0.14	0.14	-0.95	0.341
ot2: First Look: Age Group	-0.04	0.14	-0.26	0.797
ot3: First Look: Age Group	0.58	0.15	3.96	<0.001
ot4: First Look: Age Group	-0.32	0.14	-2.20	<0.05

"ot" refers to the orthogonal time terms, such that ot1 refers to the linear term, ot2 the quadratic, ot3 the cubic, and ot4 the quartic

4.1.5 Discussion 2

The time course data provided a new perspective on children's looking dynamics to the target and distractor objects at test in the cross situational word learning paradigm. The temporal patterns found in the time course data reveal that children are constantly shifting their looking between the target and distractor objects throughout the test trial, but more so for the 14-month-olds. Although we did not see an overall difference in pattern based on age, we did see one based on where children started their first look, as well as an interaction between age and first look location. As we suspected, children who looked first to the target object generated a higher proportion of looks to the target throughout the trial and more so compared to children who started the test trial looking to the distractor object. The results indicate that over the course of the trial participants accumulate more time looking to the object they look at first when the trial starts. With this said, the infants did shift their looking over the course of the trial, with some shifts co-occurring to the onsets of the word, suggesting that that the words possibly pushed some children to look to the target. drove the change in looking. Therefore, although the analysis does not provide clear support for the conclusion that overall children had learned the word-object mappings, there remains the possibility that words are driving some children to look to the target object indicating word learning.

It is somewhat surprising that 12-month-old children who started looking to the target object had more looking to the target overall than their 14-month-old counterparts. This is particularly interesting, as previous findings from Yu and Smith (2011) and others (Vlach & Johnson, 2013) tend to show that older children generate significantly more looking to the target object than their younger counterparts. In most developmental literature, age tends to be a significant factor with children improving as they get older. Although it is not unheard for younger children to perform better depending on the task, in the cross situational literature this has not been the case. This age discrepancy between our findings and the cross situation word learning literature may be another fault of the task. In addition, the non-replication of overall word learning in Experiments, 1, 2, and 4, along with the non-replication in Experiments 2 and 4 of the relation between training trial looking dynamics and stronger learning performance, we believe speaks more to the failure of the task to account for how children learn words than a failure of our experiments. To further this point, the large number of drops due to fussiness, low looking levels, and side biases regardless of testing time, attention grabbers, and stimulus used leads us to believe infants around this age range may not be suitable to test in this procedure. In addition, if the experiment cannot be completed by large numbers of participants, it is safe to assume that the participants kept in the study may not be a true representation of how children look, attend, and possibly learning in a cross situational word learning task. With all the reservations about the task said, the looking dynamics of learned and non-learned word-objects found across all three cross situational experiments provides an interesting insight into how children’s looking behaviour may relate to learning word- object mappings.

Chapter 5: General Discussion

5.1 Overview

We began this study in the hopes of increasing our understanding of how visual exploration during naming relates to word learning. Prior work by Yu and Smith had suggested that differences in looking dynamics over training, in particular sustained attention as measured by fewer, longer looks to objects during training, was related to overall learning in the cross situational word learning task. The idea is that this pattern of stable looking enables infants more time to look at the objects while hearing the words, which, over time, allows them to form strong word-object associations. In contrast, infants who shift attention back and forth between the objects do not gain the valuable time looking at the objects when the words are presented. This leads to weaker associations and often with the incorrect pairing between the object and the word (Yu & Smith, 2011). However, our three experiments suggest this relationship is not robust. Although we found evidence of fewer fixations with longer looking bouts being related to more learning in Experiment 1, this effect was not replicated in Experiments 2 or 4. Rather, in those studies strong and weak learners had similar max fixation length and number of fixations. If this type of sustained attention is a vital component to cross situational word learning, we should have seen a more consistent finding among number of fixations and max fixation length. The fact that we did not indicates that either this pattern is not as fundamental or there are other patterns of behaviour that account for word learning. This idea fits with the fact that Yu, Zhong, and Fricker (2012) did not find sustained attention leads to successful word learning in a cross situational word learning study with adults, but instead found selective attention to previously seen objects was critical. Adults were able to remember previously seen word-object pair that then further drove looking to these pairs, allowing them to accumulate more time to form and retaining the word-object mappings. It may be that sustained attention leads to selective as both lead to accumulating more time looking to objects over training. Thus, sustained attention may not be the only mechanism leading to strong word learning, but possibly is related to other looking dynamics such as time accumulated with objects over training.

More concerning, perhaps, is the fact that across our three experiments we failed to replicate the overall finding of word learning in the cross situational paradigm. In all three studies infants, as a group and separated by age, showed equal looking to the target and distractor at test. Notably, Smith and Yu have replicated their original (2008) finding of cross situational word learning in two other studies with infants and an adult study; in

2011 and 2013 they found overall word learning in 12- to 14-month-old old infants, along with looking dynamics that led to better learning outcomes, and in 2007 they found that adults show robust word learning in a variety of cross situational word learning conditions. Furthermore, dozens of prior studies have demonstrated word learning in variants of the cross situational word task learning with children (Akhtar & Montague, 1999; Suanda, Mugwanya, & Namy, 2014) and adults (Truewells, et al., 2013; Gillette, Gleitman, Gleitman, & Lederer, 1999; Suanda & Namy, 2012). Notably, however, the Smith and Yu studies are the only studies demonstrating cross-situational word learning in children at 12-months, and our Experiment 4 was a veridical replication of Smith and Yu (2008) including use of their stimuli via video.

Furthermore, it is well known that non-replications are harder to find in the literature (Francis, 2012; Maxwell, 2015; Schmidt & Oh, 2016; Perone, 2019) due to publication bias and the replicability crisis. Two recent poster presentations report studies with failures to replicate cross situational word learning in 18-month-old (Verde, Antovich & Graf-Estes, 2019) and 5-year-old (Benitez & Lalani, 2019) children. We believe it is likely that similar failures to replicate cross situational word learning with infants exist but have gone unpublished, leading the literature to show predominately studies with word learning success.

At the very least, then, it is clear that infant, and perhaps toddler, word learning from cross situational word learning paradigms is a not robust effect. To further this point, the large number of drops due to fussiness found in Experiments 1,2, and 4 may also speak to the effects found and the paradigm of cross situational word learning. Since several children were unable to complete the task despite changes in trial length and stimuli used suggesting that this paradigm may be too taxing for this age range. That said, we believe there may be useful information to be gained via further examination of the relation between visual attention and exploration during training and how this relates to test performance. In particular, this thesis did consistently find a relation between looking during training and test performance at the level of looking to objects associated with learned and non-learned words for strong and weak learners. Specifically, we found that strong learners looked more to the objects that matched words that they went on to demonstrate having learned at test and weak learners looked more to objects that matched words they did not demonstrating having learned at test. This effect was evident in the first block of training and is particularly striking as it suggests greater looking to the objects that corresponded to learned words may be present at the at the start, rather than developing over the course, of training. As we noted earlier in chapters 2 and 4, looking to objects that correspond to words that strong learners indicate word learning for at test may have occurred by happenstance. However, the continued looking to these same objects over training suggests two possibilities for what is driving looking dynamics and two different conclusions about learning in this paradigm. One possibility is of association learning through sustained attention and one of object preferences where infants did not truly learn the word- object mappings.

Similar to canalization (Gottlieb, 1991), it may be that strong and weak learners start the experiment with the same experience and knowledge; however, it is only when they make their first look do they start down the path that leads to strong or weak word learning. Along this line of reasoning, strong word learners start the experiment simply looking to one object, maybe due to individual preference, and through this long bout of looking they gather several bits of information, such as the its associated word/s. Over multiple presentations they keep looking to the object, slowing building the word- object association. Once they have this word-object mapping, they may then start to look to other objects, slowly accumulating more looking time and enabling time to hear the corresponding word. Then at test, upon hearing a word, they look toward the object they associated with that word during training, indicating word learning.

The second possibility presents a similar story based on the same looking data. Strong and weak learners both start the experiment with the same knowledge and information and looking more to a selective number of objects. Over the course of training both strong and weak learners continue looking the same objects trial after trial, accumulating looking time. At test strong learners continue their preferential looking regardless of the word present, but it just so happens that the target object is the preferred object leading to more looking time. Weak learners, however, at test switch their looking to objects they have yet to accumulate a lot of looking time for. That is, it is possible that the difference between strong and weak learners is that at test learners continue to look to the objects they have preferred throughout training, while weak learners demonstrate a preference to switch to novel things at test. Although we would like to conclude that what drives the looking differences at test is indicative of word learning, both possibilities are derived from the same learned and non-learn word-object looking data. These results were consistent across all three of our studies, ages, and stimuli suggesting that these looking dynamics are a robust effect.

The time course analysis provided more insight into infants' looking patterns during the test trials. This analysis suggests that younger infants (12-month-olds) tend to have stickier attention, whereas older infants shift back and forth more often. The shifts in attention do not perfectly map onto the onset of the words, i.e. there is not always a shift in looking to the target object after a word onset, however this suggests that infant looking may not be driven by the word-object association. The time course analysis did detail where infants start the trial looking matters, in that first look can further shape looking during the rest of the trial. In fact, infants that started looking to the target object were able to accumulate more time despite some looking to the distractor at time points. However, infants who start looking to the distractor objects do not build up enough looking time to the target over the test trial.

The results from the child discrimination study further supported the findings that where you start the trials looking can affect looking throughout the trial. Children who started looking to the change side on the test array, accumulated more looking time to the change beasties, indicating higher levels of discrimination. Although this effect of first look varied depending on the dimension, step, and age of the child, as there were significant shifts to the change side indicating that there were levels of discrimination of the beastie objects.

5.3 Future Directions

The results of the current thesis provided a new perspective of how attention and preference can shape looking and possibly learning in a cross situational word learning paradigm. Although these topics of attention and preference are not new to the field of word learning nor cross situational word learning, this thesis provided a relatively new interpretations and analyses of children's looking in a cross situational experiment, to which there is more to be explored. The results from Experiments 1 and 2 suggest that infants as a group did not show evidence word learning, but individuals who appeared to have learned some of the mappings could be found. These strong learners maintained attention to objects throughout training that they would go on to demonstrate having learned the words for at test. We could not conclude from our experiments if this was sustained attention and association learning or simply object preference, but for both accounts the difference in strong and weak learners may have started from the very first trial of the experiment. The time course data in Experiment 4, indicating that where infants start the trial looking can shape and affect looking throughout the trial, with infants who start the test trial looking at the target object end the trial with more overall looking to the target object. This experiment also provided some evidence that 12-month-olds have stickier attention than 14-month-olds who shift their attention more. Although from our experiments we could not conclude whether infants' looking and attention suggested learning or object preference, we believe that future work could.

We suggest future work should test the constraints of this paradigm to ensure its validity of a task. As we discussed, our cross situational experiments had a large number of drops suggesting the task is difficult for 12 to 14-month-olds to complete. Although, Smith and Yu were able to find word learning in this group using 6 word-objects pairs, this may be too many word-objects for this age range. We suggest limiting the number of word- object pairs to a set of four to test if more children would be able to complete the task and possibly show higher levels of word learning.

Future work will also need to identify whether infants' looking over training and at test is indicative of word learning, which can be achieved through a different experimental designs and analyses. In order to test if infants' looking is driven more by objects than words, experimenters could simply remove words at test. If infants' looking to objects in a test without words show similar looking dynamics to infants who heard words at test this would suggest words are not driving looking. Another study design to test whether looking is object or word driven could vary the object pairings at test based on looking in training. This line of work could discover if children could overcome object preference and look to the target word-object. An example test trial could pair a highly attended object as a distractor with a low attend object as the target. If children have learned the word for the highly attended object they should look more to the target object, but if object preference drives their looking they would continue to attend to the distractor.

An alternative route for future research would be to perform time course analyses on the patterns of looking during the training trials, specifically focusing on how the onset of words during training influences looking behaviour. During training two objects are presented along with two words. Some research (Yu, et al., 2012), in addition to our own, has shown that participants start attending to certain objects more than others very early in training, possibly forming an early word-object mapping. Researchers could track looking over training, to see whether looking changes when the words come on or if it remains stable. In addition, it would be important to examine whether there are differences in the influence of words during the early relative to the later parts of training. For example, Yu and colleagues found that adults shift their attention to objects after the onset of the word.

Therefore, if children are learning these mappings we should see a trajectory where children shift to the target object over training if they are learning the mapping. Although, Smith and Yu (2013), did look at the time course analysis after the onset of the word it was done on the varying versus repeating data. This study was particularly designed to test novelty effects, and this changes the structure of the object and possibly the looking dynamics. Therefore, it would be interesting to see how the looking trajectory would occur as infants are able to shift their attention creating novel or familiar object preferences or word-object mappings. Lastly, if research does indeed find sustained attention and few shifts between objects leads to higher levels of word learning, future work can guide children's attention by highlighting objects to draw infant's attention thus supporting longer looking bouts and thus more word learning.

5.4 Conclusion

This thesis has explored the role of attention and object preferences in influencing looking in a cross situational word learning paradigm. Although our results cannot conclude that children can learn words via a cross situational experiment, we instead can conclude that children's attention and preferences led to differences in looking dynamics, which possibly support and enable word learning. This work opens up many avenues for further study into object preferences and visual attention and memory on infant word learning and cross situational word learning.

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Appendix

Table 8 Lists comparisons across cross situational experiments

		Smith & Yu, 2008	Yu & Smith, 2011	Exp 1	Exp 2	Exp 3
Methods	**Participants Age**	12 & 14mo	14mo	14mo	12 & 14mo	12 & 14mo
	Number	28, 12mo (13 males) Mean:12.07 Range:11.17-13.0			24, 12mo (12 males) Mean:12.09 Range:11.14-12.95	22, 12mo (17 males) Mean:11.70 Range:11.04-13.01
		27, 14mo (14 males) Mean:14.12 Range: 14.2-15.14	18, 14mo (10 males) Mean: 14.20 Range: N/A	23, 14mo (13 males) Mean: 14.38 Range:13.09-15.20	23, 14mo (10 males) Mean: 14.27 Range:13.18-15.05	30, 14mo (14 males) Mean: 14.88 Range:13.90-15.48
	Attention grabbers	3 s*	3 s*	3 s	3 s	4 s
	Coding	Frame-by-frame	Eye-tracker	Frame-by-frame	Frame-by-frame	Eye-tracker
	Object/Object Movement	Novel Shapes/ Jiggle	Novel Shapes/ Jiggle	Beasties/ Static	Beasties/ Jiggle	Novel Shapes/ Jiggle
Training Trials	**Number of Trials and length**	30 trials 4 s	30 trials 4 s	30 trials 4 s	30 trials 4 s	30 trials 4 s
	Number of words	2 words	2 words	2 words	2 words	2 words
	Average Looking /Ratio	12mo: 3.27s /0.82	3.02s /0.75 S: 2.96s /0.74 W: 3.07s /0.77	3.32s /0.83 S: 3.37s /0.84 W: 3.27s /0.82	12 mo: 3.16s /0.79 S: 3.07s /0.77 W:3.36s /0.84	12 mo: 3.03s /0.76 S: 2.84s /0.79 W:3.15s /0.71
		14 mo: 3.04s /0.76			14 mo: 3.24s /0.81 S: 3.26s /0.81 W:3.20s /0.80	14 mo: 3.07s /0.77 S: 3.08s /0.77 W:3.06s /0.76
	Percent looking to both sides for 1000 ms	87%	N/A	53%	12mo: 52%	12mo: 41%
					14mo: 52%	14mo: 50%
	Average Number of Fixations	N/A	3.28 S: 2.75 W:3.82	2.74 S: 2.58 W: 2.90	12mo:2.91 S:3.02 W:2.80	12mo:3.07 S:2.97 W:3.17
					14 mo:2.78 S:2.83 W:2.71	14 mo:3.43 S:3.63 W:3.23
	Max Fixation Length	N/A			12mo:1.78s S:1.65s W:1.91s	12mo:1.78s S:2.27s W:2.01s

			1.45s S: 1.69 s W: 1.21s	2.12s S:2.26s W:1.98s	14mo 1.80s S:1.76s W:1.84s	14mo 2.11s S:2.11s W:2.12s
Test Trials	**Number of Trials and length**	12 trials, 8s	12 trials, 8s	12 trials, 10s	12 trials, 7s	12 trials, 8s
	Number of words	4 times**	4 times**	4 times	4 times	4 times
	Average Looking (seconds) and Ratio	12mo: 5.60s /0.7			12mo: 4.83s /0.69	12mo: 4.64s /0.52
		14mo: 6.10s /0.76	5.92 s/0.74	6.81 s/ 0.68	14mo: 4.92s /0.70	14mo: 4.94 s /0.62
	Target/ Distractor Looking	12 mo T: 3.20s /D: 2.40s			12 mo T: 2.50s /D: 2.33s S: T: 2.43s /D: 2.07s W: T: 2.65s /D:2.94s	12 mo T: 2.32s /D: 2.43s S: T: 2.55s /D: 2.19s W: T: 2.09s/ D:2.66s
		14 mo T: 3.60s/ D: 2.50s	T: 3.25s/ D: 2.67s	T: 3.45s /D: 3.63s S: T:3.75s /D: 3.27s W: T: 3.07s /D: 3.59s	14 mo T:2.46s /D:2.46s S: T:2.67s /D:2.16s W: T:2.15s /D:2.93s	14 mo T:2.43s /D:2.58s S: T:2.61s /D:2.24s W: T:2.24s /D:2.92s
Word Learning	**Number of words learned (Number of children)**	4 words	3.5 words S: N/A (12) W: N/A (6) 6 words (0) 5 words (4) 4 words (6) 3 words (4)	3.13 words S: 3.6 words (10) W:2.77words (13) 6 words (0) 5 words (0) 4 words (7) 3 words (12) 2 words (4)	12mo: 3.22 words S: 3.88words (17) W:2.57 words (7) 6 words (1) 5 words (3) 4 words (8) 3 words (8) 2 words (3) 1 word (1)	12mo: 2.90 words S: 3.75words (12) W:1.90 words (10) 6 words (0) 5 words (3) 4 words (4) 3 words (8) 2 words (3) 1 word (4)
					14mo: 2.93 words S: 3.64 (13) W: 2.22 (9) 6 words (0) 5 words (3) 4 words (5) 3 words (9) 2 words (2)	14mo: 2.79 words S: 3.50words (16) W: 2.07words (14) 6 words (0) 5 words (1) 4 words (8) 3 words (11)

	2 words (1) 1 word (2)	1 word (0)	1 word (3)	2 words (5) 1 word (5)

* Cited at 3 seconds, but inspection of the video revealed to be 4 second in length
** Cited to repeat 4 times, but inspection of the video reveal words repeated between 4 to 7 times

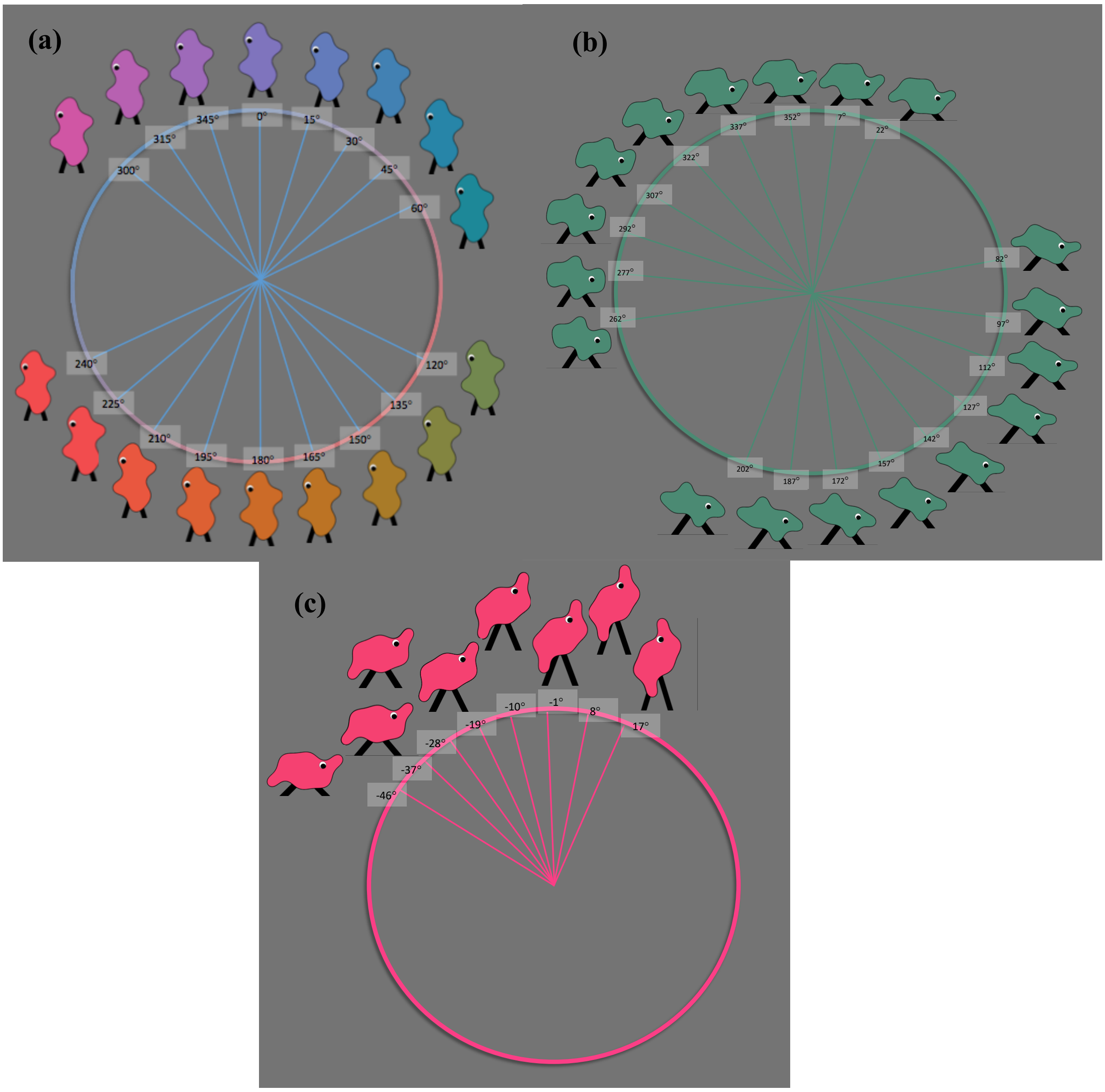

Figure 35. **(**a) The 18 images used for the colour beasties, sampled from the continuous colour wheel every 15-degrees. (b) The 18 images used for the shape beasties, sampled from the continuous shape wheel every 15-degrees, (c) The 8 images used for the orientation dimension beasties, sampled from the continuous orientation wheel every 9-degrees.

Adult Discrimination model with gender

There was a reliable main effect for change look, indicating that participants looked significantly longer on the change compared to the non-change side; t(9861)=71.10, p<0.001. There was also a reliable main effect of dimension, such that that participants looked longer to both the colour and orientation changes than the shape changes; t(9840)=3.44, p<0.001and t(9838)=2.30, p<0.05, for colour v. shape and orientation v shape respectively. Lastly, there was a main effect of step, such that a step 1 (15°) change received less looking than a step 2 (30 °) change, t(9840)=-3.93, p<0.001.

There was a reliable two-way interaction of change look and dimension. Participants looked significantly longer on the change side with the colour and orientation sets compared to shape set; t(9841)=14.91, p<0.001, t(9840)=13.92, p<0.001, respectively. There was a reliable two-way interaction of change look by step. Participants looked significantly less for step 1 compared to step 2, t(9843)=-17.55, p<0.001, step 2 compared to step 3, t(9839)=-3.11, p<0.01, and step 3 compared to step 4, t(9840)=7,87, p<0.001. There was a reliable two-way interaction for change look and gender, such that males had significantly less looking to change side than females, t(9861)=-3.70. p<0.001.

A reliable three-way interaction emerged between change look, dimension, and step, t(10236)=2.42, p<0.05, as well as, change look step and gender, t(10236)=3.61, p<0.001. Lastly, there was a reliable four-way interaction between change look, dimension, step, and gender, t(10237)=-3.40, p<0.001. These interactions were unpacked by examining the two-way interactions between change look and step, and three-way interactions for change look, step, and gender, for each dimension (Colour, Orientation, and Shape).

For colour, there was a reliable two-way interaction for change look and gender, where males had significantly less looking to change side than females, t(3298)=-2.70. p<0.01. In addition, there was a reliable three-way interaction for change look step and gender, t(3272)=-3.40, p<0.001. This interaction was further investigated by examining the two-way interaction for change look and step by males and females. Both males can females had significantly looking to the change side, t(1514)=33.35, p<0.001 and t(1817)=41.34, p<0.001, respectively. In addition, both males and females had a significant two-way interaction for change look and step, where there was significantly less looking to change side for step 1 compared to step 2, males: t(1494)=-9.32, p<0.001, females: t(1812)=-5.25, p<0.001, step 2 to step 3, males: t(1493)=-8.49, p<0.001, females:

t(1812)=-6.29, p<0.001, and step 3 to step 4, males: t(1488)=-4.96, p<0.001, females: t(1810)=-2.92, p<0.01.

For orientation, there was no significant effect of gender.

For shape, there was a reliable three-way interaction for change look, step and gender, t(3725)=2.19, p<0.05. This interaction was unpacked by examining the two-way interaction for change look and step for males and females. Both males can females had significantly looking to the change side, t(1608)=10.50, p<0.001 and t(1959)=14.14, p<0.001, respectively. In addition, both males and females had a significant two-way interaction for change look and step, where there was significantly less looking to change side for step 1 compared to step 2, males: t(1605)=-4.36, p<0.001, females: t(1958)=-5.45, p<0.001, step 2 to step 3, males: t(1606)=-3.86, p<0.001, females: t(1959)=-8.42, p<0.001, and step 3 to step 4, males: t(1606)=-4.29, p<0.001, females: t(1959)=-7.19, p<0.001.

Including gender into the main model found similar result to that of the main model, where participants were able to discriminate across all dimensions and this ability increase with step. However, with the inclusion of gender, it was found that female participants performed better than that of their male counterparts by spending more time looking to the change side. This could be seen in the colour and shape dimensions, as well as across gender.

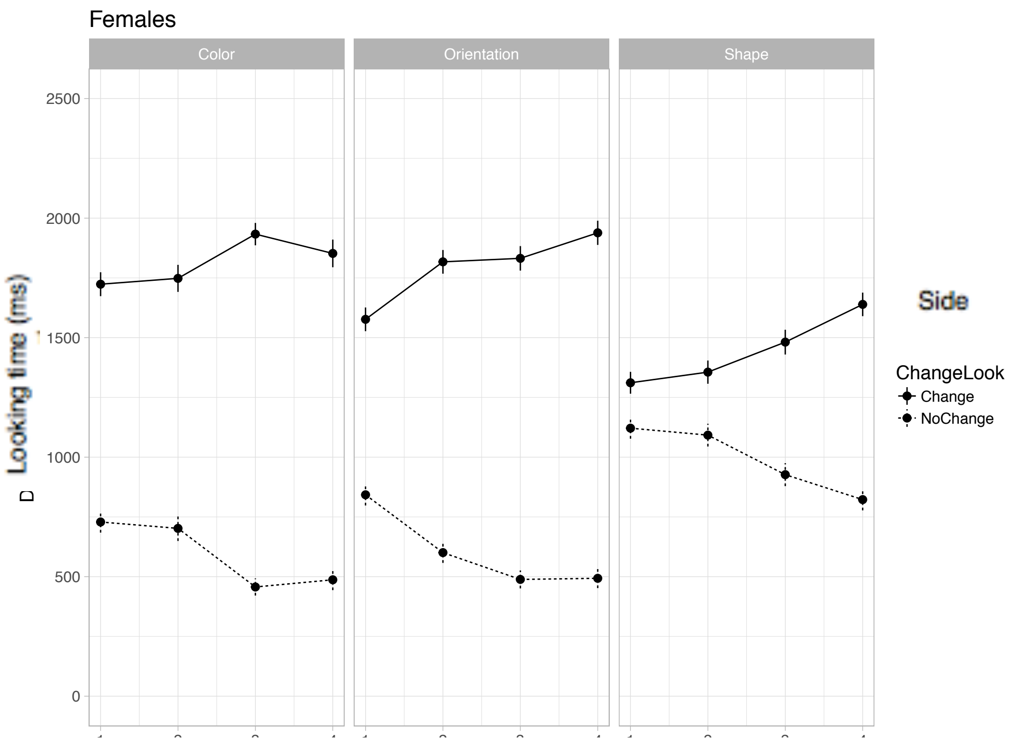

Figure 36. Looking to the change and no change side by dimension for adult female participants.

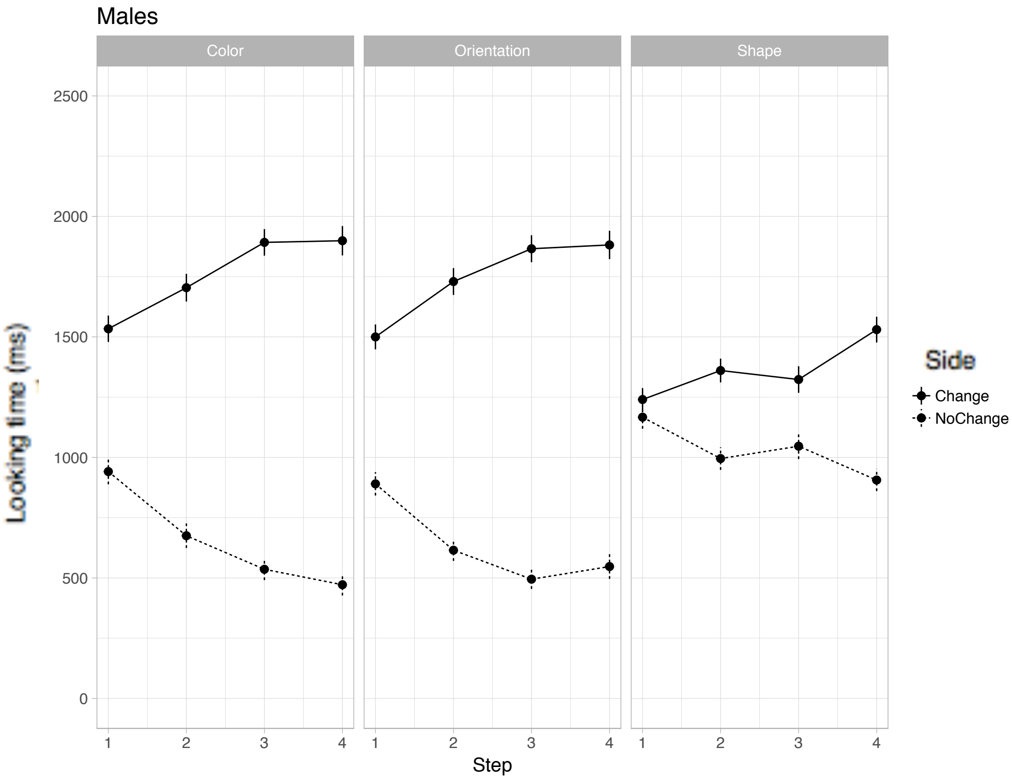

Figure 37. Looking to the change and no change side by dimension for adult male participants.