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5- AND 8-MONTH-OLDS' VISUAL EXPLORATION OF 2D SCENES: THE RELATIVE IMPACT OF OBJECT SIZE, OBJECT DETAIL, AND DEPTH CUE ON INFANTS' VISUAL ATTENTION

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I am submitting herewith a dissertation written by Yu Guan entitled "5- AND 8-MONTH-OLDS' VISUAL EXPLORATION OF 2D SCENES: THE RELATIVE IMPACT OF OBJECT SIZE, OBJECT DETAIL, AND DEPTH CUE ON INFANTS' VISUAL ATTENTION." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Psychology.

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Abstract

How infants visually explore complex scenes containing objects varying in size, depth cues, and amount of detail is still an open question. When infants are presented with a complex scene, we do not know which dimensions of the scene are more likely to catch their attention first, and which are more likely to sustain their looking duration the most. This study aimed to investigate how infants' explore 2D displays containing different combinations of object size, depth cues, and detail.

In experiment 1, forty infants (twenty of 5 months old and twenty of 8 months old) were presented with stimuli containing different combinations of object sizes, linear perspective depth cues, and details. In experiment 2, another twenty infants (ten of 5 months old and ten of 8 months old) were presented with stimuli with the detail removed from the objects. An eye-tracker was used to examine: 1) the location and latency of first look, and 2) the look duration on each object.

Results showed that the **first look data** were consistent with prior studies (e.g. Cohen, 1972; Guan & Corbetta, 2012) revealing that when the objects were of different sizes, infants first directed their visual attention to the large object in the scene despite other information. When objects sizes were identical, infants directed their attention first to the object with details. **Look duration data** showed that the object size was also the main factor holding infants' attention, but it interacted with object detail and background depth cues. For instance, when detail was added to the large object, infants sustained their attention longer to that object than when no detail was present.

In sum, the current study showed that object size had priority in catching and holding infants' visual attention. However, when size was controlled, detail became the

attention getter. Adding detail to the object might increase the power of object size to hold infants’ attention. Depth cue did not catch or hold infants’ attention when size and detail were present in the scene. Thus, there might be a hierarchy order between size, detail, and depth cue on infants’ visual attention.

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Chapter 1 Introduction

1.1 Background and theoretical accounts

Vision is one of the most unique and important senses available to us for exploring and learning about the world. The majority of people rely heavily on vision in their daily lives. Good vision is necessary for reading, navigation within the environment, and even to detect danger in the environment, promoting survival. It has been suggested that more than half of the adult brain is responsible for processing visual information (Sereno et al., 1995). In infancy vision is critical for learning and influences behavior. For instance, visual attention in infancy can be an indicator of temperament and self-regulation (Posner & Rothbart, 2007), which are related to future learning capacities. Infants use visual information to detect object shape and patterns (Fantz, & Nevis, 1967; Posner & Keele, 1968; Cohen, 1972), to categorize objects such as animal species (Quinn & Eimas, 1996b; Younger & Cohen, 1983), to detect depth cues when they navigate through the cluttered environment (Bertenthal & Campos, 1994), and to obtain knowledge about objects, such as object unity (Kellman & Spelke, 1983; Amso & Johnson, 2006) and object permanence (Baillargeon, 1987b). Without vision, learning about the world would be much more difficult for infants. For instance, blind infants show less interest in exploring objects and toys because they are unable to achieve eye-hand coordination and thus do not receive the same amount of stimulation as sighted infants (Fraiberg, Smith, & Adelson, 1969).

Interest in object perception originated in the nineteenth-century with the development of the theory of structuralism, proposed by Wilhelm Wundt (Titchener, 1921). The tenet of the structuralism theory was that perception arises from assembly of

sensory primitives through a process of associations of those primitives in time and space. These associations are formed from early life experience including exposure to objects. In other words, complex perceptions are formed through the consolidation of basic visual information. For example, we perceive a face as a result of the integration of a number of parts such as eyes, nose and mouth. We perceive a dog because we incorporate important parts of the dog such as the torso, ears, tail, and legs into the image of a dog. The structuralist approach, which dominated psychology until the 1920s, stimulated the emergence of Gestalt psychology. In opposition to structuralism, Gestalt psychologists suggested that the whole is not only the summation of its parts (Wertheimer, 1912). Gestaltists proposed that we organize visual scenes into figure and ground, but perception is based on the holistic features of the objects. Gestalt principles include several rules of perceptual organization that describe how visual elements spontaneously organize themselves to make sense of the visual scene. For instance, in the law of good continuation, Gestaltists proposed that lines are perceived to be continuous even when they are occluded by objects. Tree branches will be perceived to be continuous although they are behind a trunk if their Gestalt suggests continuity. The theories of structuralism and Gestalt psychology shed some light on the mechanisms of perception. They suggested that the visual system could either integrate small elements within a scene to form a big picture, or break the large chunk of visual information into smaller pieces.

In the twentieth century, researchers further developed theories of object perception. Three theories were especially important and contributed to our understanding of perception. First, J. J. Gibson's ecological approach emphasized the importance of the ambient visual environment and its role in perception (Gibson, 1977).

He suggested that we utilize external environmental information to perceive objects. As an example, imagine someone is driving along a street. As the car moves forward, the visual pattern of the surroundings, such as the trees and houses, moves backward. Thus the formation of this optic flow provides useful information to control the driving speed and direction. Another example can be seen in the formation of depth perception. J. J. Gibson suggested that formation of depth perception could be the result of the association between visual input and locomotion. Given that the retinal image of an object becomes constantly bigger as we move closer to it, we develop an understanding of the relationship between object size and depth as we move toward objects. Similarly, since the retinal image of an object becomes smaller as we move further away, we construct a new relationship between object size and depth as we move away from objects. Therefore, based on ecological approach, depth perception can be influenced by our daily locomotion experience. To further explain the inseparable relationships between our perception, action, and the environment, J. J. Gibson introduced the term “affordance” (Gibson, 1977). Affordance indicates, for example, that objects that are graspable or a chair that is sit-on-able. With typical development, infants’ vision should afford the perception of information necessary to action. In short, J. J. Gibson emphasized the importance of environmental information and the relationship between perception and action. We use visual information from our environment to guide our actions. At the same time, we act within the environment in order to gather new information.

In addition to J. J. Gibson, E. J. Gibson expanded upon the concept of perceptual learning to include infant perceptual development. E. J. Gibson is known for conducting the “visual cliff” study, which tested infants’ depth perception (Gibson & Walk, 1960).

The “visual cliff” is a platform with a textured checkerboard pattern. The pattern appears to be four feet higher on one side of the platform, called the shallow side, than the other side, called the deep side. A large piece of glass extended evenly across both sides of the platform. Infants were put in the middle of the platform at the edge of the shallow side and were encouraged to move across the deeper side of the platform. This study found that infants with crawling experience did not go to the apparently deeper side of the visual cliff, indicating they were sensitive to depth cues provided by the textured checkerboard patterns. The most important contribution of the visual cliff study is that it illustrated a relationship between infants’ early self-guided locomotion experience and their formation of depth perception. Navigating independently through the environment might provide unique opportunities for infants to perceive and construct relationships between movement and depth, which may facilitate infants’ formation of depth perception. In sum, E. J. Gibson, together with J. J. Gibson, presented perception in a more environment-related context showing that perception is necessary for viewing information within the environment, planning actions, and guiding us to achieve our goals.

In addition to the importance of the external environment on our perception, Jean Piaget shifted our attention to the question of how perceptual learning occurs. In his influential developmental theory, he emphasized the role of learning in developing and coordinating perception. He proposed step-like progress in the perception of objects and made connections between perception and cognitive knowledge. Piaget (1953) said of perception:

> “Perception of light exists from birth and consequently the reflexes which insure the adaptation (the pupillary and palpebral reflexes, both to light). All the rest (perception of forms, sizes, positions, distances, prominence, etc.) is acquired through the combination of reflex activity with higher activities.” (p.62)

According to Piaget (1953), infants organize knowledge in schemas, through which they can process and comprehend the environment. When infants are confronted with new information, they first try to use their existing schemas to incorporate the information into their knowledge. This is a process called assimilation. However, when their existing schemas cannot explain the new information, they need to develop new schemas. This is a process called accommodation. This stage-like, part-to-whole progression is called constructivism, which allows infants to build a complex, hierarchical knowledge base for future behavior. In sum, according to Piaget’s constructivist theory, infants’ perception and cognition of the world follow a stage-like, simple-to-complex, progression.

Beginning with the work of Piaget, researchers have tried to explore the changes that underlie perceptual and cognitive development during infancy. The information processing movement has been inspired by computer technology and is based on the idea that the human can operate like a computer to process and analyze information from the environment (Goodwin, 2005). Several steps take place during visual information processing and include attention mechanisms responsible for bringing information into the system, working memory for actively manipulating information, and long term memory for storing information.

Many studies have investigated how infants encode visual information. For example, Cohen conducted pioneering work using the information processing perspective to study infants' perception and cognitive development (Cohen, 1972; Cohen & Younger, 1984; Cohen, Chaput, & Cashon, 2002). One of his contributions to the understanding of infants' perception was his proposal of an attention-getting and attention-holding information processing model (Cohen, 1972). Cohen (1972) used the paired-comparison method to test 4-month-old infants' visual preferences to checkerboards with varied numbers and sizes of checkers. The study found that infants first shifted their visual attention to the checkerboard with larger checks. But they spent a longer time looking at the checkerboard with more checks on it. These findings provided evidence that infants had distinctive underlying processes for checker size and number. Thus, Cohen proposed that object size has an attention-getting property. Larger objects catch infants' attention faster than smaller objects. Object number has an attention-holding function: infants look longer at displays with more objects. This two-process attention model has established the roles of object size and number in determining infants' visual responses. More importantly, it inspired researchers to examine infants' visual attention to multiple components.

Cohen's attention-getting and attention-holding model strongly suggested that visual attention is a multi-component construct instead of a unitary phenomenon. Similarly, Colombo proposed that attention in early development could be divided into at least four independent functions or processes: Alertness/arousal, visuospatial orienting, object perception, and endogenous attention (Colombo, 2001a; Colombo & Cheatham, 2006). Each of these four components has its own function and is mediated by different

neural structures. Specifically, alertness/arousal reflects the preparedness of the attention system for accepting new information and is mediated by various ascending brainstem pathways (e.g., Robbins & Everitt, 1995). Visuospatial orienting contains the disengagement, shifting, and engagement of attention, and depends on posterior attentional network (the “where” network; Posner & Petersen, 1990). The process of object perception involves analysis, binding, and recognition of stimulus features, and is controlled by extrastriate and temporal structures (the “what” network; Colombo, 2001a). Lastly, voluntary control reflects the process of integrating and coordinating activation of various attentional components (Colombo & Cheatham, 2006). This process is mediated by frontal lobe structures (Rueda, Posner, & Rothbart, 2005).

Around the same time that Cohen proposed his two-phase attention model, psychophysiologists were using the heart rate method as a measure of attention (Graham, 1970, 1979, 1992; Porges, 1976, 1980; Richards, 1987). Richards measured infant heart rate to study attention and proposed a five-phase model of infants’ visual attention (Richards & Casey, 1992). According to this model, infants’ visual attention involves five sequential phases that occur during a single look to a stimulus: pre-attentive, stimulus orienting, sustained attention, pre-attention termination, and attention termination. The pre-attentive phase includes a detection system, which directs attention to the stimulus. It is followed by the stimulus orienting phase, lasting for 4 to 5 seconds, characterized by a rapid drop in heart rate. This phase represents the beginning of attentional engagement and includes limited information processing. The sustained attention phase then takes place, characterized by a prolonged lowered heart rate. This phase involves the activation of the arousal system and cognitive information processing

of the stimulus. In the attention termination phase, infants may continue to look at the stimulus but no longer process the information. The heart rate begins to return to pre-stimulus level. This is the final phase of attention.

Both Colombo's and Richards' models share many similarities with Cohen's two-process model from his behavioral studies. For instance, visuospatial orienting is influenced by attention-getting properties of stimuli (e.g., Posner, Inhoff, Friedrich, & Cohen, 1987). One example is that infants might first direct their visuospatial orienting response to the larger object in the scene (Cohen, 1972). On the other hand, attention-holding properties may elicit sustained attention, which is defined by a combination of looking and heart rate deceleration (Richards, 1987). For instance, infants take longer to disengage from a central stimulus to distractors during sustained attention, which is a component of active information processing. In sum, infant visual attention is not a unitary process. We might study infant attention under an attention-getting and attention-holding framework.

Cohen's two-process theory not only inspired others to examine the multiple components of attention, but also contributed to the exploration of the importance of object perception on future cognitive development. Based on the information processing idea, Cohen and his colleagues proposed six information processing principles of cognitive development (Cohen, Chaput, & Cashon, 2002). In their principles, Cohen and colleagues state that infants are born with information processing systems. Infants start learning about low level information such as color, shape, movement. Cognitive development follows a hierarchical order, such that higher level units are formed from the

integration of lower level units. With the development of higher level units, infants become more capable of processing complex information.

Cohen's information processing principles have been tested in several infant perception and cognition studies. One example is in research on early form perception of an angle (Cohen & Younger, 1984). In this study, infants of 6-14 weeks were habituated with two lines arranged in the form of a 45-degree angle and then were tested with a variety of angles and relations between the two lines. The results showed that older infants perceived the angle as a unit, while younger infants perceived the angle only as two separate lines. Using the visual preference method, this study demonstrated a developmental trend from processing the stimulus based on lower level units (the lines) to processing based on higher level units (angle). In all, Cohen's information processing principles suggested that infants' perceptual and cognitive development follows a low to high, simple to complex procedure.

From a different perspective, system theories propose a multi-causal idea of early development. For example, according to ideas of Schneirla, Kuo, and Gottlieb, behavioral development is the outcome of an interaction of internal and external factors (e.g., Gottlieb, 2009; Gottlieb, Wahlsten, & Lickliter, 2006; Kuo, 1970; Schneirla, 1966). Following the systems theory approach, dynamic systems theory argues that the brain and body are coupled in the environment and interact dynamically over time. This is known as the concept of embodiment (Chiel & Beer, 1997). Thelen (2000) also highlighted embodiment and mentioned that cognition is embodied. It rises from bodily interactions with the environment. Cognition depends on experience that comes from one's perception and motor abilities that are inseparably linked and together form a matrix that

reasoning, memory, emotion, language and all other aspects of mental life are embedded within. The incorporation of systems theories into theories of development in infancy has encouraged a more unified, multi-causal perspective of early development.

There are two critical features of the dynamic systems theory. First, development is multi-causal and self-organized. Changes in our behavior are caused by multiple factors. Second, development is non-linear with variable stability. The stability of the system is determined by how tightly the components are tied together. If something disrupts the stability, the relationships among all of the components will change and new patterns will be formed.

Although the dynamic systems theory has been widely applied to infant motor development (Thelen, 1985, 1989, 1994, 2000; Thelen & Corbetta, 1994, 2002), it might also be helpful in the explanation of perceptual development because the visual system is also multi-causal and self-organized. A lot of factors contribute to visual activity. For example, internal factors necessary to the ability to see an object include good postural control required to stabilize the head and body, the activation of attention in order to process the information, previous knowledge to understand the information, etc. These are all internal factors. There are also external factors that contribute to object perception. For example, when the object or the scene is changed, infants' visual exploration might be changed too. Thus, if we look at infants' perception and knowledge from the dynamic systems perspective, they are "softly assembled" within a particular task context through the interaction of dynamic process (Thelen & Smith, 2006). Perception is tied to its context; how infants perceive the size of an object depends on surrounding objects as

well as background information. In other words, when the context is changed, infants' visual behavior might be changed as well.

Over the past 100 years, our knowledge of visual processing has changed, developed, and been further investigated. Structuralism and Gestalt theories first guided us to take a close look on how adults perceive objects: whether we perceive objects by integrating small bits information together or by breaking large chunks of information into smaller pieces. Later, J. J. Gibson and E. J. Gibson emphasized the inter-relationships between perception, action, and the external environment. They stressed the importance of external stimuli and their unique influences on infants' perceptual behaviors. Recent studies from the constructivist and information processing theories combined with computational models have indicated that infants become more capable of processing complex information as they integrate low level units into higher level units. By combining the information above, we should also be able to use the dynamic systems view to explain infant visual attention from a different perspective; by integrating both external factors, such as environmental stimuli, with internal factors, such as physical maturation of the visual system, we will cultivate a greater understanding of infants' visual attention and its development.

1.2 Visual attention development during the first year

Infants are born with poor visual abilities. Their visual system is functionally effective but structurally immature (Bonds, 1979). Newborns' visual acuity is forty times worse than that of typical normal adults. Nonetheless, newborns are able to perceive complex visual patterns (Fantz, 1965). Their visual system is under the control of the *reflexive system*, including the lateral geniculate nucleus, primary visual cortex, and

superior colliculus (Atkinson, 2000; Banks & Salapatek, 1983; Hickey & Peduzzi, 1987; Schiller, 1998; Reynolds, Courage, & Richards, in press). During this period, with poor head control, newborns do not have much ‘freedom’ to voluntarily disengage their visual attention easily. There is a phenomenon called ‘sticky fixation’ characterized by trouble shifting attention from one object to another object and caused by immaturity of the visual system (Hood, 1995). Although newborns are not experienced perceivers, they show visual preferences for large and salient stimuli. For instance, they look longer at patterned than unpatterned stimuli (Fantz, 1963). They also prefer to look at larger squares compared with smaller ones (Bronson, 1990; Salapatek, 1975).

Around two and three months of age, the first major developmental transition of the visual system takes place. Infants’ visual acuity and flexibility increase due to the rapid neurological development of the visual system including the retina and several visual pathways, coinciding with longer alert periods (Reynolds, Courage, & Richards, in press). Infants begin to show less reflexive and more voluntary looking behaviors (Colombo, 2001). Thus, the salience of the size preference decreases and instead infants tend to look at more detailed objects, such as bulls-eyes.

From three to six months of age, the posterior orienting system becomes functional (Posner & Peterson, 1990). The retino-cortical visual pathways and the striate cortex also show rapid progression at this time (Hainline, Turkel, Abramov, & Lemerise, 1985). Milner and Goodale (1993, 2008) call this the orienting/investigative system of attention, which contains two interrelated components: the spatial orienting network (the “where” pathway) and the object recognition network (the “what” pathway). The “where” network, which gets information from the magnocellular layer of the lateral geniculate

nucleus (LGN), is used to detect object location in the environment, such as if the object is at the top or bottom of the scene. This network can also mediate the visual system's detection of and orientation to salient object features such as object size. The "what" network, on the other hand, gets information input from the parvocellular layer of the LGN, and is responsible for observing detailed object information. In all, under the control of these two more advanced networks, sticky fixation disappears and instead infants show "adult like" saccades (Hainline et al., 1985) and shorter fixations (Salapatek & Kessen, 1966). Four-month-old infants shift their attention from one stimulus to an adjacent stimulus more frequently than three-month-olds. Infants demonstrate greater visual selectivity and flexibility to engage and disengage from one stimulus to another at this age.

After six months of age, the anterior system becomes functional, which is responsible for higher level, voluntary control of visual attention. This is due to increased functionality of frontal brain activity in the orbitofrontal cortex, dorsolateral prefrontal cortex, and anterior cingulate cortex (Bell & Fox, 1994; Chugani, 1994; Posner, 1995). During this period, infants' looking duration to simple objects decreases, whereas look durations to complex objects increase due to increased visual capacity (Courage, Reynolds, & Richards, 2006; Ruff and Saltarelli, 1993). Infants at this age show a decline in look duration for simple white and black dots but increased look durations for Sesame Street videos and faces (Courage et al., 2006).

Colombo's (2001a) tri-phasic theory of look duration fits well with the three attentional systems described above. His study provided evidence that fixation length increases from birth to two months because infants have poor control of their visual

exploration behavior, and then decreases from three to six months because the onset of the posterior orienting system which enables infants to have more visual flexibility. After six months, infants reach a plateau in looking duration. Also stimulus type has a significant influence on looking duration after this age. Infants prefer dynamic, more complex stimuli. Similarly, Courage et al. (2006) tested this tri-phasic theory using three different types of stimuli including computer generated patterns, faces, and Sesame Street. Each type of stimuli was presented in both static and dynamic conditions. The results supported the tri-phasic theory showing a decrease in look duration between three to six months of age. After six months of age, stimulus type had a significant effect on infants' visual behaviors.

In summary, rapid maturation of the visual systems takes place during early development. The first transition happens at two and three months, with the disappearance of sticky fixation and the emergence of more flexible visual scanning. Then from three to nine months of age, binocularity and visual acuity reaches adult levels (Aslin, 1987). Specifically, before six months, the posterior orienting system enables infants to orient, engage, and disengage to visual stimuli more voluntarily. From six to nine months, with increased frontal brain activity, infants show more complex visual exploration patterns. This can also be attributed to stimulus.

1.2.1 Perception of object size

Infants' visual preferences during the first year of life have been studied for more than fifty years. The role of object size in visual exploration might be one of the earliest questions that have been tested. Unlike adults, infants cannot tell us what they prefer to look at, thus the design of the test is very important. The visual preference task, which

was developed by Fantz in the 1960s, is an effective design to test infants' visual preference and is still being used today. In studies using a paired comparison preference task to investigate the impact of object size on infant looking behavior, infants are presented with two differently sized objects on the left and right of the screen. Looking preferences are determined by the time spent looking to each stimulus. Using this method, studies have shown that infants younger than two months attend to stimuli based on stimulus size: they prefer to look longer at large squares (Fantz, 1965; Salapatek, 1975; Bronson, 1990).

Studies investigating both looking and reaching have provided some insight into infants' preferences based on stimulus size while reaching for objects (Newman, Atkinson, & Braddick, 2001; Yonas, Cleaves, & Pettersen, 1978). For instance, Newman and his colleagues (2001) conducted a study in which they presented infants with two cylinders of different diameters to test their looking and reaching preferences. They found that infants tended to shift their first fixation to the larger cylinder and also reach for the larger cylinder.

Cohen (1972) also demonstrated that object size plays a role in catching older infants' (four-month-olds) visual attention, but he suggests that it might not always hold infants' attention if the scene possesses the factor of object number as well. Object size was proposed to be an attention-getting property because a larger object is more salient than a smaller object. This is a rapid early visual orienting response that requires little information processing. However, Cohen also proposed that when stimuli contain varying object sizes and numbers, infants will sustain their attention to the stimulus with more components rather than the larger stimulus.

In conclusion, based on these previous studies, object size is a very salient stimulus property that grabs infant attention. Stimulus size will determine infants’ first look in most of conditions even if other factors (e.g. object number, depth cues) are present. Infants’ bias to initially respond to large object is a fast orienting response that requires little information processing. However, infants’ sustained attention to the large object might be affected by other visual factors. When sustained attention is investigated, the function of object size needs to be determined with the influences of other visual elements.

1.2.2 Perception of object detail

Object detail is another important topic studied in the infant perception literature. Together with object size preference studies, these studies share a common interest in exploring underlying information processing mechanisms active during infants’ visual behaviors and have helped to further understand the development of attention and cognitive development. For instance, in Fantz’s (1963) study, he discovered that newborns looked longer at patterned stimuli than at plain fields of color. Also, using the paired-comparison paradigm, he found that infants preferred to look at more complex patterns such as a bull’s-eye than other simple patterns (Fantz, Fagan, & Miranda, 1975; Fantz & Nevis, 1967). These results were later verified by other researchers who showed that older infants focused their visual attention on smaller areas with more detail than on larger simpler areas (Miranda, 1970; Hainline & Abramov, 1992; Ruff & Birch, 1974; Ruff & Turkewitz, 1975).

While studies on infants’ visual preferences conducted during the 1960s and 1970s amassed a plethora of data, researchers were looking for a model to unify and

explain infants' visual behaviors. As mentioned previously, Cohen's attention-getting and attention-holding model was one of the earliest models to suggest the information processing mechanisms of infants' visual behaviors. It established that infants' visual attention is not a uniform process, but that it has at least two components. First, larger objects catch infants' attention faster than smaller objects, thus object size has an attention-getting property. Second, increased object number can hold infants' attention longer. Thus, infants' visual attention should be able to be measured by separate variables, such as first look, latency of the first look, and look durations.

Based on the behavioral data, unifying models were proposed trying to fit all the results in one theoretical framework. The complexity theory was one of them. According to the complexity theory, object complexity was defined based on the amount of details per unit area and infants' information processing capacity was proposed to increase with age (Dember & Earl, 1970). During the first year of life, older infants have higher density of receptor cells in the fovea than younger infants, illustrated at successive levels in the visual pathway (e.g. Garey & De Courten, 1983). Accordingly, older infants showed a greater interest in looking at more complex patterns than simple patterns (Brennan et al., 1966; Greenberg & O'Donnell, 1972; Greenberg & Weizmann, 1971). Thus, complexity theory emphasized physical maturation as the main factor that leads information processing abilities to increase.

Another model that has been proposed is the neural substrate theory (Karmel & Maisel, 1975). According to this model, response rates of neurons in the central visual system determine infants' visual capacity (Fantz et al., 1975). Neurons will be activated only when visual patterns match the neurons' receptive fields. In other words, the visual

system will selectively "choose" the patterns that fit its processing ability and spend a longer time exploring them. More detailed patterns are preferred as infants get older because the receptive fields become finer with age. The similarity between the complexity theory and the neural substrate theory is that both suggest that the preference for more detailed/complex patterns increases with age due to physical maturation of the visual system.

Although the models above contributed to our understanding of infants' visual behavior, the complexity theory and neural substrate theory have some limitations. For instance, the neural substrate theory does not specify how to measure infants' information processing capacity (for review see Banks & Ginsburg, 1985). To improve upon the ideas developed in these models, some computational models based on engineering techniques have been proposed including the linear systems preference model (Banks & Salapatek, 1981) and the Cascade Correlation and Sibling-Descendant Cascade-Correlation networks (Schultz, 2011).

The linear systems preference model was designed to test and predict infants' visual responses to a variety of patterns (Banks & Salapatek, 1981). This model assumed that infants' visual preferences are determined by the pattern information available to decision centers in the central nervous system. In other words, how well the pattern passes through the infants' filtering function determine infants' visual preferences. The linear systems preference model reanalyzed a great deal of behavioral data including Cohen's checkerboard study (Cohen, 1972) and Fantz and Fagan's studies (Fantz & Fagan, 1975). This model was able to predict infants' visual preferences more accurately than older models for various patterns.

In addition to the linear systems preference model, the Cascade Correlation (CC) network and Sibling-Descendant Cascade-Correlation (SDCC) network are two recently proposed models that seem to be particularly useful for understanding infant visual preferences (Schultz, 2011). The Cascade Correlation network begins with input and output units and expands while learning, by adding new hidden units into the network (Shultz, 2003). The Sibling-Descendant Cascade-Correlation network is newer than Cascade Correlation network that decides where to add the new layer, either on the current highest layer or on its own highest layer (Baluja & Fahlman, 1994). These two models have been created in conjunction with constructivist accounts of development and are consistent with main features of infant data. Again, these models reinforce the belief that infants' perceptual and cognitive development follows a simple to complex procedure.

The successes of these computational models, together with a large amount of behavioral studies, suggest that there is a general principle underlying the infants' perceptual and cognitive development characterized by a general trend from lower to higher level processing and from simple to more complex. With the development of remote eye-trackers, studies of infants' visual preference have become more direct and accurate than ever before. With this new technology, we are able to answer more complex questions regarding infants' visual processing than could be attempted earlier. Researchers who used the paired comparison paradigm previously could only ask questions that were restricted to at most two components, such as size or number, complex or simple objects. Asking questions about infants' visual behavior within a scene composed of more elements is more challenging for research design. However by

testing infants' visual behaviors using more complex scenes, researchers are able to get an idea about infants' visual behaviors under more realistic conditions. Infants are not living in a world that only has checkerboards or bull's-eye patterns. They live in a real, complex world with varying stimulus properties including object size, depth cues and object detail. Infants' visual behavior should be measured under more complex conditions to understand the underlying mechanisms of infants' information processing.

1.2.3 Depth Perception

Depth cues are essential in our daily life because they provide information about object size and distance as we navigate through the 3D world. Furthermore, we need to translate this depth knowledge into 2D scenes so that we can detect depth cues and understand the information presented in paintings and photographs. Thus, when we are looking at 2D pictures we know that converging lines indicate an increase in distance. Classic studies have shown that adults rely on depth cues to accurately estimate object size (e.g. Holway & Boring, 1941; Meehan & Triggs, 1988). One example is Holway and Boring's (1941) study, which demonstrated that when depth cues were progressively removed, a regression occurred in the perceived size of objects. Other studies have revealed that foreground texture served as a depth cue that was important for adults to judge the size of objects (Hull, Gill, & Roscoe, 1982; Iavecchia, Iavecchia, and Roscoe, 1983; Rock & Kaufman, 1962). Furthermore, Meehan and Triggs (1988) conducted a study, which found that as more depth cues were available, adults' overestimates of object size decreased.

Depth cues also play an important role in infants' daily perception and action. When infants start reaching, they need depth information to estimate object distance and

size in order to plan their reaching movement. When they start crawling and walking, they also need depth cues to estimate object size and distance around them to adjust their movement speed or direction in order to avoid obstacles. Researchers have studied the early development of depth perception systematically and suggested there are three types of depth cues available to infants: kinetic depth cues, binocular depth cues, and monocular depth cues (Yonas, Cleaves, & Pettersen, 1978). Previous research has demonstrated that infants gain access first to kinetic depth cues, then to binocular depth cues and finally to monocular depth cues.

Newborns are able to perceive depth using kinetic depth cues (Ball & Vurpillot, 1976; Náñez & Yonas, 1994). Picking up kinetic depth cues require movement of the eyes or the head of the perceiver, including optic contraction, expansion, and motion parallax. For example, motion parallax happens when infants move their heads and static objects nearby move more slowly than distant objects, providing cues about the distance and depth. Infants of two months of age have been able to react to objects using only motion parallax as a depth cue (Bower, 1965).

Infants begin to explore binocular depth cues between three to four months of age (Bushnell & Boudreau, 1993). Binocular depth cues can be conveyed in two ways: retinal disparity and convergence. Specifically, retinal disparity indicates that images on the left and right retinas appear slightly different. Differences between the two images provide depth information about the 3D world. Convergence is the inward movements of both eyes when fixing on a single object moving toward the eyes. Convergence increases as the object gets closer to the eyes. The visual system sends signals to the brain to evaluate the effect of this convergence and calculate the distance between the object and observer.

Eye muscle maturation is necessary to perceive binocular depth cues at this age (Bushnell & Boudreau, 1993).

The third way, and latest way to develop perceived depth is by monocular depth cues, including *relative size* and *linear perspective* depth cues. These depth cues can be illustrated on 2D displays to provide information about depth and are known as pictorial depth cues. Animal studies conducted on rats and chicks have suggested that newborn animals do not respond to pictorial depth cues in the visual cliff paradigm (Gibson & Walk, 1960). Similarly, infants do not react to pictorial depth cues until the middle of their first year. Many studies have been conducted to test the onset of infants' pictorial depth cues perception (e.g. Granrud, Yonas, & Opland, 1985; Yonas, Elieff, & Arterberry, 2002; Yonas & Granrud, 2006; Yonas, Pettersen, & Granrud, 1982). These researchers used a preferential reaching paradigm and presented real 3D toys on a background containing depth cues. Results demonstrated the emergence of pictorial depth perception around 5 to 7 months of age. Of particular interest to the current study is work done looking at the development of infant sensitivity to relative size and linear perspective depth cues, which is reviewed below.

Relative size

Relative size is a pictorial depth cue that is seen when looking at two objects of the same size, but at different distances in the 3D world. The nearer the object is, the larger it appears because of the larger visual angle. Similarly, on 2D displays, even though two objects are of the same distance to an observer, larger objects seem closer than smaller ones. Since binocular depth information weakens the effect of relative size information, these depth cues are stronger under monocular conditions after removing all

the binocular depth cues. Thus, when adults are covering one eye and are presented with two objects of different sizes but same distance to them, they report the larger object is closer to them: only relying on the depth cues of relative size enable them to judge that the larger object is closer to them than the smaller object (Wilcox & Teghtsoonian, 1971). However, when adults are able to use both eyes to observe the same scene, they can use binocular depth cues to attenuate the relative size depth cue so that observers will report correctly that two objects are at the same distance.

According to the findings of the first group of studies, infants' sensitivity to relative size depth cues appears between 5 to 7 months of age (e.g. Yonas, Cleaves, & Pettterson, 1978; Yonas, Granrud, & Petterson, 1985). In Yonas, Cleaves, & Pettersen's (1978) study, infants' perception of relative size depth cues was tested using the Ames window. The Ames window was a trapezoidal shape with two vertical sides of different length but at the same distance from observers. When adults looked at the window under a monocular condition, they reported the longer side of the window is nearer than the shorter side. This is because they judged the distance of the sides only by relative size depth cues. Interestingly, when infants were presented with the Ames window, seven-month-old infants reached more to the shorter side of the window under the monocular condition, but there was no reaching preference observed under the binocular condition. Five-month-old infants showed no reaching preference under either monocular or binocular conditions. The results of this study provided evidence that the sensitivity to relative size depth cue is not an innate ability. Infants are only able to use this type of depth cue after 5 months of age.

Relative size depth cues have also been tested in infants using two different size objects such as circles or squares that are presented at same distance from the infants. In Yonas, Granrud, & Petterson's (1985) study, infants reached for one of the objects in front of them during the test. Consistent with the Ames window study, infants older than five months of age reached more to the larger object when they wore an eye patch, which only allowed them access to the monocular relative size depth cue. When under binocular conditions, they showed an equal amount of reaching to both objects. Again, younger infants did not demonstrate reaching preferences under either condition. Thus, combined with the Ames window study, this study revealed that infants are able to use relative size depth cues around 5 months of age.

Linear perspective

Compared with other pictorial depth cues, such as texture gradient, linear perspective has the strongest influence on our perception of object size and distance (Arnheim, 1954). For instance, Arnheim claimed that the convergence of lines in paintings is the strongest cue to three-dimensionality. This type of depth cue occurs when the converging lines receding in space appear to move closer together, such as railroad tracks that converge as they appear to recede into the distance.

Research has shown that linear perspective depth perception is not an inborn ability. Early studies with people in isolated African tribes showed that they could not utilize line drawing depth cues such as converging lines to estimate the relative distances of objects (Deregowski, 1969). In addition, one group of infant studies suggested that the emergence of the linear perspective depth cue perception is also seen around 5- to 7-months of age. For example, Yonas and his colleagues (2002) tested infants with two 3D

toy dolls suspended in front of a 2D textured background with converging lines receding in depth in both monocular view and binocular view conditions. They discovered that 7-month-old infants reached less to the object at the converging lines of the depth cues under monocular conditions. However, 5-month-old infants did not show reaching preferences to one of the two objects. Again, these results revealed that linear perspective depth cues only affect older infants' perception of object size. Similar findings were observed in a longitudinal study, confirming that infants react to linear perspective depth cues between 5 to 7 months of age (Yonas, Elieff, & Arterberry, 2002).

As indicated based on the studies described above, researchers have investigated infants' depth perception based on relative size and linear perspective depth cues and concluded that understanding distance and size information represented by pictorial depth cues in 2D displays require a greater time (around 5 months) to develop than kinetic and binocular depth perception. However, another group of researchers used looking methods, including habituation-dishabituation or preferential-looking methods, and came to divergent results (Granrud et al., 2007; Durand, 2003; for review see Kavsek, Yonas, & Granrud, 2011). These studies have shown that infants respond to pictorial depth cues as early as four months old. For example, Granrud et al. (2007) tested 3- to 7-month-old infants' visual responses to a toy moving diagonally in front of a textured background. The animation included a consistent condition and an inconsistent condition. In the consistent condition, the toy's size changed consistently with the depth background (e.g. the toy becomes bigger when it moves closer). Conversely, in the inconsistent condition, the toy's size change was inverse to the depth cues background (e.g. the toy becomes smaller when it moves closer). Four-month-old infants and older infants looked longer at

the inconsistent display and thus the authors concluded that the onset of pictorial depth cue sensitivity is before 5 to 7 months. Another study conducted by Durand et al. (2003) habituated three- and four-month-old participants to a static display, in which relative size information conflicted with pictorial information (e.g. the closer box appears to be smaller than the distance box). Similar findings showed that 4-month-old infants looked longer during the habituation period to the inconsistent display.

Recently, we used eye-tracking technology to examine this question by presenting 2D slides containing different combinations of object size and pictorial depth cues in the background to 8-month-old infants (Guan & Corbetta, 2012). In the study, infants were seated in an infant chair 267 cm away from a large screen (102 cm height x 151 cm width). Slides of different conditions were presented sequentially to the infants for 5 sec each. Our conditions were as follows:

1. Different-size congruent depth cues: object size was scaled consistently and gradually with linear perspective depth cues so that the largest object was at the bottom and the smallest object was at the top.
2. Different-size reversed depth cues: the object size was reversed to the depth cues information so that the smallest object was at the bottom and the largest object was at the top.
3. Different-size no depth cues: three objects (largest was at the top and smallest was at the bottom) were scaled with no depth cues in the background (parallel lines were used as a control for depth cues).
4. Same-size depth cues: objects of the same size were scaled with the depth cues in the background with the lines converging to the top of the scene.

5. Same-size no depth cues: objects of the same size were scaled with no depth cues background (parallel lines were used).

We looked at their first fixation on each slide to see which object feature (e.g. size) caught their attention first. At the same time, we looked at their longest look duration to the objects to see which object feature kept their attention longest. The first fixation results indicated that the largest object had an attention-getting property. Specifically, when the three objects were of different sizes, infants' first fixation went to the largest object on the slide irrespective of whether depth cues were provided or not. When the three objects were of the same size, infants' did not show a preference on the first fixation to any specific object on the slides. On the other hand, our look duration data showed that there was an interaction between object size and depth cues. Specifically, when the three objects were of different sizes, infants spent the longest amount of time looking at the largest object, but only when depth cues were provided. When depth cues were removed, the infants spent an equal amount of time looking at the three objects. In the condition with three objects of the same size, infants did not demonstrate a looking preference when depth cues were absent. However, when the three objects were of the same size and the background contained linear perspective depth cues, infants looked longer at the object that was at the converging end of the depth cues, presumably because it appeared larger. In all, the results of this study supported Yonas et al.'s (2002) results by demonstrating that infants are sensitive to pictorial depth cues by 8 months of age.

During the 5-second visual exploration of each slide, infants were able to attend to object size and the depth cue, such that the depth cues led to prolonged visual attention to the largest object. When the depth cues were removed, this phenomenon disappeared.

This phenomenon was also seen in a follow-up study conducted with 4- and 6-month-old infants, which found that infants increased in sensitivity to depth cues with age (Guan & Corbetta, manuscript in prep). Once again, based on the look duration analysis, we confirmed that sustained attention is the product of information processing that was affected by both object size and depth cues. Object size alone did not have enough power to hold infants' attention on that object longer. Infants become sensitive to linear perspective depth cues as early as 4 months of age.

1.3 Focus of the current study

A plethora of infant visual attention studies and models since the 1960s have contributed significantly to our understanding of infants' visual exploration of 2D displays. Based on the information processing theory, we know that infants' visual attention is a complex process. Object size has the salience to initially grasp infants' attention, during the initial orienting response that involves little information processing. Pictorial depth cues can have a strong effect on object size perception during active information processing. Also, the sensitivity to the depth cues becomes progressively stronger during the first year of life due to infants' increased information processing abilities. In addition, infants' ability to process complex, more detailed information increases with age. However, we only have pieces of information on infants' perception of size, depth cues, and amount of detail. Infants are living in a complex visual world containing all these three factors. What if we combine and manipulate all these three components together and test infants' visual reactions? Specifically, when object size, depth cue, and object detail are mixed in a 2D display, what will initially attract infants' visual attention? Which factor is going to hold infants' attention longer than others? How

will infants scan between the objects when details on the objects are present or absent? Using the eye-tracking method allows us to find the answers of these questions in a more accurate and direct manner. By studying infants' visual responses to complicated 2D information, we will have a better understanding of how infants integrate more complex information and thus the underlying mechanisms of infants' information processing processes.

To put the pieces of all of the puzzles together, a dynamic systems approach can be used. From a multi-causal perspective, behavioral development is the outcome of the neural processes interaction with other external factors (Gottlieb, 2009; Gottlieb, Wahlsten, & Lickliter, 2006; Kuo, 1970; Schneirla, 1966). Furthermore, Chiel and Beer's (1997) embodied idea presented the similar idea that cognition rises from the bodily interaction with the outside environment and is continuously interacting with it. Thus, visual behavior is the result of interactions among many components, such as neural pathways, cognitive abilities, and motor development. All of these components count, and none of them are privileged (Thelen, 1992; Thelen & Smith, 1994, 2006). For example, in order to perceive and understand pictorial depth cues, both external factors (e.g. relative size, depth cues, object details) and internal factors (e.g. physical maturation of the visual system, experience) play important roles. Dynamic systems theory stresses both internal and external components. For example, in Guan & Corbetta's (2012) recent study, infants' visual responses to object size differed under conditions when depth cues were presented or not. Specifically, infants' visual exploration was affected by the integrated effect of object size and background depth cues. Thus, when the new external factor, pictorial depth cues, was added to the scene, the visual pattern was changed

accordingly. On the other hand, older infants shifted their visual attention to the objects faster than younger infants did, suggesting the internal factor also contributed to the changes of infants' looking behaviors.

The dynamic systems theory has already been widely applied to infant motor development (Thelen, 1985, 1989, 1994, 2000; Thelen & Corbetta, 1994, 2002). It might also be helpful for explaining perceptual development because eye movement behavior is also multi-causal and self-organized. In other words, the visual system is a multi-causal, self-organized, non-linear system with variable stability. The stability of the system is determined by how tightly the components are cohering. When something disrupts the system's stability, components shift into new patterns. For instance, when the context is changed, such as adding or removing depth cues, or adding detail to the objects, the stability of the system will be changed and these components will reorganize and form new looking patterns. Thus, infants' visual preference is complex and context dependent. When the context (i.e. object size, depth cues, details) is changed, infants' looking patterns might be changed during information processing.

In the current study, the effects of object size, pictorial depth cue, and object detail in 2D displays are examined in 5- and 8-month old non-crawlers' looking patterns. According to the literature on infant depth perception, infants react strongly to pictorial depth cues between 5 and 7 months of age, and their sensitivity to pictorial depth cues increases during the first year of life. Thus, by testing 5- and 8-month-olds we are able to observe the developmental changes of depth perception and the effect of infants' visual exploration of other elements. Only non-crawlers were used in the current study because several studies have suggested that crawling experience might affect infants' depth

perception (Berthental, Campos, & Kermoian, 1994; Gustafson, 1984). Thus, controlling crawling experience was necessary to eliminate the motor effects on depth perception.

The questions investigated in the current study are as follows:

1) When the object detail is added to object size and pictorial depth cues in a 2D display, how will infants respond to the more complex information?
2) How will infants' visual responses change over time from 5 to 8 months old of age?

Because visual attention must be examined based on multiple components, this study primarily investigated two different aspects of visual exploration: 1) the first look, and, 2) sustained attention to objects in the scene.

The expectation for the first look analysis is that object size will singularly have the power to grasp infants' attention first, which would replicate our earlier results (Guan & Corbetta, 2012). That means that infants in both age groups might display significantly more first looks toward the large object regardless of the object detail and depth cue information. This is because responding to object size, as compared to the other two factors, is an initial visuo-spatial orienting response, which requires little information processing (Cohen, 1972; Newman et al., 2001, Guan & Corbetta, 2012). In addition, the magnocellular pathway is responsive to the size information to a greater extent than detail information (Goodale & Milner, 2004). However, when object size is controlled, infants are expected to direct their attention first to the detailed object. This is because when the size is controlled, details might become the most salient factor to infants' visual attention. Differences in first looks are also expected with age; older infants are expected to shift

their first visual attention faster to the first object than younger infants because of their improved scanning ability and flexibility.

The results of sustained attention are rooted in the theoretical notion that the visual response is context dependent and can be affected by changing external factors. When more complex information is added to the scene, the context is changed and the visual response may be changed accordingly. The parvocellular pathway, which is responsive to object details, might interact with the magnocellular pathway to affect infants' visual responses (Goodale & Milner, 2004). Thus, adding detail to the objects might change infants' looking patterns to the objects. In particular, depth cues and details should interact with object size and thus influence infants' looking durations. For example, when objects are of different sizes, pictorial depth cues are provided in the background, and details are provided on the large object, the pictorial depth cues and detail information might increase the power of object size to hold infants' attention on the large object. Thus, infants might look significantly longer at the large, detailed object in conditions that provide depth cues in the background. However, if details are added to the small object, this detail information might compete with and decrease the saliency of the large object so that the large object might not hold infants' attention to the extent that it did before. In other words, infants might look significantly less to the large, non-detailed object in the detail-on-small-object condition compared with looking time to the large, detailed object in the detail-on-large-object condition.

Chapter 2 Experiment 1

2.1 Method

2.1.1 Participants

Forty infants were used in Experiment 1, including twenty 5-month-old (±1 week) infants and twenty 8-month-old (±1 week) infants. None of the infants had started crawling at time of study. There were equal number of males and females within each group. All infants were recruited from the Knoxville, Tennessee, area through mailings and follow-up phone calls. Names were obtained through a state-supplied database. An additional 5 infants were brought to the laboratory but were excluded from the analyses due to fussiness (N=2), improper eye movement calibration (N=2), or lack of useable eye tracking data (N=1). Among the sample that yielded useable data, 39 participants were white and one was African American. All the infants were born full term and were free of visual impairments. All parents consented to have their infants participate in this study, and they received a photo and certificate for their participation.

2.1.2 Material

A custom-made infant seat, reclined ten degrees from vertical, was used to support the participants in front of the testing apparatus. A wide foam strap around their torso provided full trunk support while permitting a full range of head movement. When participants were seated in the infant chair, their eye level was approximately 74cm above the ground.

A small wooden table (64 x 38 x 38 cm, width x depth x height) covered with a piece of black cloth was located in front of the infants. A remote eye-tracking device (Tobii x50, Tobii Technology, Inc., Danderyd, Sweden) was placed in the middle of the

tabletop. The lens of the eye-tracker was 60cm away from the infants' eyes in order to get the best eye signal. The eye-tracker tracked at what point on the slides the infants were looking by using corneal reflection. Eye tracking was done at 50 Hz, with an accuracy of 0.5 degrees. Under the table, a Dell 3400MP projector (Dell Inc., TX, USA) was used to project stimuli on a large, white, horizontally-standing cardboard screen (102cm height x 151cm width) located 267cm in front of the participant. This distance was the same as in Guan & Corbetta (2012) in order to compare the results between the two studies. Infants could not see the projector since it was covered by the black cloth on the table. A speaker was placed behind the projection screen. The eye-tracker, projector, and the speaker were all connected to a computer operated by an experimenter in an adjacent room.

There were 5 pieces of custom designed panels, each measuring 205 cm (height) x 155 cm (width), connected together to create a theater to enclose the projection screen and the infant to minimize distractions from the environment. The infant was seated at the opening side of the panel and the projection screen was located at the other end (see figure A1).

A video camera, which was connected to the monitor in the experimenter's room, was located behind the infants' seat. The function of the video camera was to let the experimenter see from another room if the infant was looking at the screen during the calibration and test sessions. This is especially useful during calibration since the experimenter needed to know if the infant looked at the stimulus for an accumulated 3s so that he/she could change to the next calibration stimulus. The whole set up was the same as per Guan & Corbetta (2012) (see figure A1).

2.1.3 Design of stimuli

There were eighteen conditions in Experiment 1. Each slide contained two objects, one at the top and the other at the bottom. Within the eighteen conditions, twelve of them were different-size conditions with one small object and one large object on every slide. Each different-size condition contained a combination of three factors: depth cues, orientations, and details.

Three depth cues conditions:

1. Congruent depth cues (Con): This condition included the slides that depicted the object size and depth cues which were consistent with one another. Two objects (large, small) were scaled gradually and consistently with the linear perspective depth cues in the background. That means that the large object was always at the opening side of the lines indicating the depth cues, and the small object was always at the converging side of the lines. This condition depicted the scenes as infants would typically see them in the natural environment.
2. Reversed depth cues (Re): This condition included slides that had object size and depth cues that were not consistent. That means that the large object was always at the converging side of the depth cues lines and the small object was always at the opening side of the depth cues lines.
3. No depth cues (No): Parallel lines were used as a control for depth cues.

Two orientation conditions:

1. 0^{o}: The depth cues lines were always converging to the top of the slide.
2. 180^{o}: The depth cues lines were always converging to the bottom of the slide.

Two detail conditions:

1. DS: Details on the small object
2. DL: Details on the large object

Three dots were added to one of the objects in every slide to represent detail. To control the color/brightness contrast of the dots on the object to be the same level across all the stimuli, only black dots on white objects or white dots on black objects were used. Also, all the objects were black or white on a white or black, high contrast background. Thus, the color contrast between the object, dots, depth cues, and background were all black and white to keep the brightness contrasts consistent across all the slides.

Below are the slide IDs of all the different-size conditions. The naming of the slide IDs follows the description of depth-orientation-detail:

Diff: Con-0-DS, Con-0-DL, Con-180-DS, Con-180-DL (see figure A2)

Diff: Re-0-DS, Re-0-DL, Re-180-DS, Re-180-DL (see figure A3)

Diff: No-0-DS, No-0-DL, No-180-DS, No-180-DL (see figure A4)

The rest of the six conditions were the same-size conditions, which contained two objects of the same size in the scene. Below are listed all the same-size conditions. The naming of the slide IDs follows the description of orientation-detail.

Same: 0-DT, 0-DB (see figure A 5, two top rows)

Same: 180-DT, 180-DB (see figure A 5, two middle rows)

Same: No-DT, No-DB (see figure A 5, two bottom rows)

All the slides were projected on the white cardboard screen (visual angle: 20.6 degrees vertically, 27.0 degrees horizontally) for 5s each.

For the eighteen conditions, each condition had three display directions: vertical, diagonal to the left, and diagonal to the right. One of the three directions for each condition was randomly assigned to a set of the stimuli so that there were 3 sets of original stimuli (ST01, ST11, ST21). Each set contained eighteen slides. In other words, each infant was presented with eighteen slides of different conditions with randomized display directions. The reason that not all three displays for each condition were presented to each subject is simple: infants have a narrow time window of sustained attention. If every subject was presented all the conditions and displays, there would be eighteen conditions times 3 displays for a total of 54 slides. Infants at the testing ages in this study had difficulties keeping their attention for such long time.

Within each original set of stimuli, the eighteen slides were shuffled to make two or three more different sets so that ten sets of stimuli were used:

ST01, ST02, ST03, ST04

ST11, ST12, ST13

ST21, ST22, ST23

Thus, each stimulus set contained eighteen slides with depth cues pointing to random directions. Each set was used twice for two different subjects in both 5- and 8-month-old age groups.

On all the different-size conditions, the height of the large object (30 cm, visual angle 7.5) was twice the height of the small object (15 cm, visual angle 3.75). On all of the same-size conditions, the height of both objects was 22.5 cm (visual angle 5.63).

Across all conditions, the center point of the screen had equal distances (27 cm) to the center of the top and bottom objects. The center of the screen was 51 cm from the

ground and infants' eyes were approximately 51 cm from the ground. This design was consistent with most other visual preference studies, such as Fanz & Fagan (1975) and Newman et al. (2001), to provide a clear starting point to measure the latency of the first look.

Between every slide, a 2s inter slide with a smiling face at the center of the screen was presented to draw the infant's visual attention back to the center. Therefore, each stimulus set contained eighteen stimuli slides and seventeen inter slides. Music was synchronized with the slides during presentation. The presentation time for each set was 18 (stimuli slides) x 5s + 17 (inter slides) x 2s = 124s.

2.1.4 Procedure

The participants came to the lab accompanied by one or both of their parents. After the parents were explained the goals of the study and procedure, they signed the consent form. The parents also completed a questionnaire about the infant and family information to provide basic demographic information.

The participant was seated in the infant seat facing the projection screen and the eye-tracker. One parent was seated next to the infant. Before the experiment started, the projector, operated by the experimenter in the adjacent room, played an episode of *Sesame Street* to capture the infant's attention. Right after the infant started looking at the screen and the eye-tracker provided a stable signal for both eyes, the experimenter stopped the video and initiated the calibration. A 5-point calibration procedure was used. During the calibration, there was a computer-generated colored figure (i.e. duck, bee, dog) paired with synchronous sounds that expanded and contracted successively and followed the order to appear on the projection screen located at the top-left, bottom-left, top-right,

bottom-right, and center of the monitor. The presentation of each location lasted until the infant sustained their attention to the figure at that location for three seconds according to the monitor. If the infant never sustained attention for three seconds to the figure at one location within a ten seconds window, the calibration proceeded to the next location. The presentation was repeated until at least four accurate points were obtained. Otherwise the procedure was repeated on the inaccurate points. If this criterion was not achieved after several times repetitions or the participant got fussy, the participant was excluded from the study.

Once calibration was achieved, one set of the stimuli was randomly assigned to the participant and presented on the projection screen. The same set of stimuli was presented to the subject for two rounds in order to obtain enough data. Thus the total presentation time for each subject was 124s/round x 2 rounds =248s. Subjects could take a break between the two presentations if necessary.

2.1.5 Analyses

All looking data were exported by Tobii Studio v.2.0.8 (the software provided by Tobii to run the eye-tracker and analyze the data) in gaze plots, fixation tables, and videos. Dependent measures of looking behaviors were focused on (1) which object infants first looked at, (2) the latency to each object, and (3) look durations on each object.

2.1.5.1 First look

The first object visually attended to

Tobii Studio outputs a table of the first fixation, which identifies the first object infants visually fixated on. Thus, using this table, I was able to determine which objects caught infants' attention first when each slide was presented.

Latencies to the two objects

Tobii studio also exported the latencies to each object in the scene. In this experiment, the latency was defined as the time elapsed between the beginning of the slide presentation and the visual shift to each object.

2.1.5.2 Sustained attention

Each object on the slides was defined as Area Of Interest (AOI) thus each slide had two AOIs. The AOIs comprised the area of the objects as well as a one centimeter boarder surrounding the object. The looking duration within each AOI were accumulated automatically by the Tobii Studio software in milliseconds and exported to fixation tables. Thus, this measure determined how long the infants spent looking on each object during every slide's 5-second presentation time. The data was normalized by using the accumulated looking duration on the object divided by the total looking duration on the two objects on that slide. These percentages of looking duration were then compared as below:

Objects of different sizes

Infants' sustained attention on the large and small objects in the scene were compared between the three different-size conditions (congruent depth cues, reversed depth cues, no depth cues) by age groups.

Objects of same size

Infants' sustained attention on the top and bottom objects in the scene were compared between the three same-size conditions (0^{o} depth cues, 180^{o} depth cues, no depth cues) by age groups.

2.1.6 Criterion for selection of useable data

Because infants did not always provide long durations on all the slides during the whole presentation, some of the slides with short looking duration on objects were not sufficient to reveal a reliable looking pattern. Thus, I used a 3-second rule to remove slides with less than 3 seconds of accumulated looking for the two 5-second presentations. According to our previous study (Guan & Corbetta, 2012), this time duration is enough for infants to visually scan all the information within the slides. Based on the 3-second rule, 89.44% of trials (range from 77.78% to 100%, median 94.44%) were used for 5 months old subjects and 93.61% of trials (ranged from 72.22% to 100%, median 100%) were used for 8 months old subjects. In addition to this rule, subjects who had more than 50% of the slides below the 3-second criteria were removed. This is because when infants were distracted and did not pay attention to the stimuli, the data were not reliable. Based on this rule, one subject was removed.

2.2 Results

2.2.1 First look

The first object visually attended

I was first interested in which objects were initially attended by infants. The analysis was conducted within all the different-size conditions and same-size conditions separately.

Objects of different sizes

Since the normality test suggested the data was not normally distributed ($p = 0.022$; skewness = 1.30, kurtosis = -1.23), non-parametric Wilcoxon tests were used to determine whether one object on the slide caught infants' attention more frequently than

the other. The results showed that infants in both age groups tended to shift their gaze significantly first to the large object in all the different-size conditions regardless of depth cue information (congruent: 8 months: $Z = -4.72$, $P = 0.0001$; 5 months: $Z = -2.82$, $P = 0.005$; reversed: 8 months: $Z = -5.06$, $P = .0001$; 5 months: $Z = -4.24$, $P = .0001$; no depth: 8 months: $Z = -3.67$, $P = .0001$; 5 months: $Z = -3.44$, $P = .001$), as well as detail information (DS: 8 months: $Z = -4.12$, $P = 0.0001$; 5 months: $Z = -3.29$, $P = 0.001$; DL: 8 months: $Z = -4.12$, $P = 0.0001$; 5 months: $Z = -6.06$, $P = 0.0001$). Figure A6 indicates the patterns of first directed attention to one of the two objects on the slides were scaled as a function of the sizes of the objects for the two age groups. Based on these results, it shows that infants in both age groups tended to shift their gaze significantly first to the large object in all the different-size conditions regardless of other information in the scene.

Objects of same sizes

Since the data was not normally distributed based on normality test ($p = 0.035$; skewness = 1.23, kurtosis = -0.24) non-parametric Wilcoxon tests were also used for the analysis in same-size conditions. The results showed that when the two objects were of the same size, infants directed their attention first to the detailed object in both age groups in most conditions (0^{o}: 8 months: $Z = -2.42$, $P = 0.016$; 5 months: $Z = -4.81$, $P = 0.63$; 180^{o}: 8 months: $Z = -2.41$, $P = 0.016$; 5 months: $Z = -3.34$, $P = 0.001$; no depth cues: 8 months: $Z = -3.56$, $P = 0.0001$; 5 months: $Z = -1.86$, $P = 0.053$). There was no significant statistical effect of depth cues. The only exception was that 5-month-old infants did not show any first look preference in the 0° condition. Figure A7 displays patterns of the first directed attention to one of the two objects on the slide in the same-size conditions. Based

on these results, it shows that when the two objects were of the same size, 8-month-old infants directed their attention first to the detailed object while 5-month-old infants tended to first look at the detailed object in 180° and no depth cues conditions.

Latency to the two objects

This analysis was conducted in order to test if infants shifted their attention faster to one object faster than to the other object. Specifically, I was interested in determining whether latency to each object was affected by object size, background depth cues, and details. The analysis was again conducted within all the different-size conditions and same-size conditions separately.

Objects of different sizes

This measure captured the time elapsed between the beginnings of the slide presentation and the visual shift to the two objects in the scene in all different-size conditions. Since the data was normally distributed, a univariate GLM with latency as a dependent variable was used first to test the effects of displays. Since we expected that displays should not have influences on infants' exploration patterns in this study, we can combine all the displays together if no effects of displays were present. The major reason to use univariate GLM to test display effects is because this analysis, which is counted as a mixed model has a unique advantage to treat missing data. Based on the design of this study, each condition had three display directions: vertical, diagonal to the left, and diagonal to the right. Each subject was randomly assigned to watch one of the three displays for each condition (see section 2.1.3 design of stimuli). In other words, each display only had nearly 1/3 of the subjects' data for first look. In this situation with too much missing data, it is not accurate to run repeated measures GLMs to test the effect of

displays. However, using univariate GLM can analyze all of the data that is available. The missing value has no effect on other values from that same subject. If univariate GLM analysis showed no effects of displays, then repeated measures GLMs could be used to test the data by combining all the displays together.

A univariate GLM with latency as a dependent variable was used to test if displays had effects on infants' latency to the two objects. The univariate GLM contained the following fixed factors: age (5- & 8-month-olds), depth conditions (congruent, reversed, and no depth cues), detail conditions (details on the large object [DL], details on the small object [DS]), depth cue orientations (0°, 180°), and displays (vertical, diagonal to the left, diagonal to the right). No effects of displays were present in this data. Thus, repeated measures GLMs were used to test the effects of other factors after combining all the three displays. When sphericity assumptions were not met, P values provided by the Greenhouse-Geisser or Huynh-Feldt corrections were used, depending on the Epsilon value.

Results of repeated measures GLMs showed a main effect of size ($F(1, 37) = 33.48$, $p = 0.0001$, $\eta_p^2 = 0.47$) and a size x detail interaction ($F(1, 37) = 30.89$, $p = 0.0001$, $\eta_p^2 = 0.46$). Figure A8, displays these results and shows that infants in both age groups proportionally shifted their attention to the large object faster than to the small object (large: *M* = 749.63 ms; small: *M* = 1512.12 ms). Further post hoc analysis suggested that infants shifted their attention to the large object faster in the DL condition than in the DS condition ($t(19) = 5.56$, $p = 0.001$) (DL: *M* = 652.11 ms; DS: *M* = 853.13 ms).

Objects of same size

This measure captured the time elapsed between the beginnings of the slide presentation and the visual shift to the two objects in the scene in all same-size conditions. Since the data was normally distributed, a univariate GLM with latency as a dependent variable was used first to test the effects of displays.

A univariate GLM with latency as a dependent variable was used to test if displays had effects on infants' latency to the two objects. The univariate GLM contained the following fixed factors: age (5- & 8-month-olds), depth conditions (0°, 180°, no depth cues), detail conditions (details on the top object [DT], details on the bottom object [DB]), and displays (vertical, diagonal to the left, diagonal to the right). No effects of displays were present in this data. Thus, repeated measures GLMs were used to test the effects of other factors after combining all the three displays. When sphericity assumptions were not met, P values provided by the Greenhouse-Geisser or Huynh-Feldt corrections were used, depending on the Epsilon value.

Results of repeated measures GLMs showed a main effect of detail ($F(1, 38) = 15.74$, $p = 0.0001$, $\eta_p^2 = 0.17$) and location ($F(1, 38) = 15.15$, $p = 0.0001$, $\eta_p^2 = 0.20$). Figure A9, displays these results and shows that infants shifted attention to the objects faster in the DB condition than in the DT condition overall (DB: $M = 920.00$ ms, DT: $M = 1275.12$ ms). Also, they proportionally shifted their attention to the bottom object faster than to the top object (bottom: $M = 897.50$ ms, top: $M = 1297.62$ ms).

2.2.2 Sustained attention

The next question was to determine whether the infants of the two age groups kept their sustained attention on one object longer than the other object. Specifically, I

was interested in determining whether sustained attention to one object was affected by object size, background depth cues, and details. Thus comparisons of looking durations were conducted by normalizing the look duration of each toy by the total looking time on both objects on each slide. Age differences were also examined. The analysis was again conducted within all the different-size conditions and same-size conditions separately.

Objects of different sizes

Since the data was normally distributed, univariate GLM was first used to test if displays had effects on infants' looking patterns. A univariate GLM was conducted with looking time as a dependent variable and contained the following fixed factors: depth conditions (congruent, reversed, no depth cues), orientations (0^{o}, 180^{o}), detail conditions (details on the small object [DS], details on the large object [DL]), displays (vertical, diagonal to the left, diagonal to the right), object sizes (small, large), and age groups (5 months, 8 months). Results showed no main or interaction effects of displays. Thus, all the displays were combined together to do the future analysis by using repeated measures GLM. When sphericity assumptions were not met, P values provided by the Greenhouse-Geisser or Huynh-Feldt corrections were used, depending on the Epsilon value.

The results of repeated measures GLM revealed a main effect of size ($F(1, 34) = 480.50$, $p = 0.0001$, $\eta_p^2 = 0.35$), a detail x size interaction ($F(1, 34) = 163.22$, $p = 0.0001$, $\eta_p^2 = 0.23$), and an orientation x size interaction ($F(1, 34) = 25.19$, $p = 0.0001$, $\eta_p^2 = 0.39$). Figure A10, displaying the main effect of size, showed that on average, infants in both age groups looked significantly longer at the large object than the small object in the scene regardless of depth cues in the background. However, follow-up ANOVA demonstrated that infants looked longer at the large object in the DL condition than in the

DS condition (t (19) = 35.4, p = 0.0001, η_p^2= 0.25) (see figure A11). On the other hand, figure A12 displays the interaction between orientation and object size. Follow-up ANOVA suggested that when the orientation of depth cues was 0 ^{o}, which is the condition where the depth cues were converging to the top, infants in both age groups looked even longer at the large object than when orientation was upside down (180^o) (t (19) = 15.0, p = 0.0002, η_p^2 = 0.21).

Objects of same size

Since the data was normally distributed, a univariate GLM with looking time as a dependent variable, two depth conditions (depth cues and no depth cues), two orientations (0 ^{o}, 180 ^{o}), two detail conditions (details on the top object [DT], details on the bottom object [DB]), three displays (vertical, diagonal to the left, diagonal to the right), two object locations (top, bottom) and two age groups (5 months, 8 months) as fixed factors were performed to test display effects first. As we expected, no display effects were present. Again, repeated measures GLM were used after combining all the displays.

Results only showed a main effect of location (F(1, 38) = 20.80, p = 0.0001, η_p^2 = 0.35) and detail x location interaction (F(1, 38) = 46.07, p = 0.0001, η_p^2 = 0.55). As these results showed in figure A13, once the variations in the object size were absent, infants in both age groups showed a preference to look at the bottom of the display. In figure A14, follow-up ANOVA of the detail by location interaction suggested that infants proportionally looked longer at the bottom object in the DB condition than in the DT condition (t (19) = 33.10, p = 0.0001, η_p^2 = 0.25).

2.3 Experiment 1 Summary

The results of Experiment 1 contained two components: attention-getting and attention-holding. The attention-getting component was measured by infants' first look and latency to each object in the scene. The results showed that object size has the highest priority to get infants' attention regardless of object detail and depth cues. It is the most salient visual factor guiding infants' initial visuo-spatial orienting response, presumably because it requires little information processing. Posterior orienting network, which receives information from the Magnocellular layer, might be responding to the size information. When the objects were of the same size, detail became the salient factor to attract infants' attention first. Furthermore, adding detail to the large object was able to increase the power of object size to catch infants' attention faster.

The attention-holding component was measured by the look durations to the objects. Based on our prior study (Guan & Corbetta, 2012), in addition to object size, depth cues should also be able to affect infants' looking durations. However, in this experiment, infants' sustained attention in both age groups was primarily driven by object size regardless of depth cues and object detail. The disappearance of the main effect of depth cues in this experiment can be examined by comparing the designs between the current experiment and Guan & Corbetta's (2012) study. First, the discrepancy may result from the fact that in the current experiment more different-size conditions were used. In the prior study, only three different-size conditions were used: Con-0, Re-0, and No-180. In the current experiment, three more conditions were added, they were: Re-180, Con-180, and No-0. Adding these new conditions might have affected the result. To

investigate this possibility, only the three conditions used in Guan & Corbetta (2012) were tested. However, the results still revealed no effect of depth cues.

The second possibility might be that adding details to the objects made the large object too salient so that the size effect overpowered the effect of depth cues. To test this possibility, I removed all of the object detail from the slides in Experiment 2. The reasoning is that if the main effect of depth cues comes back, it might confirm that adding details to the objects overpowered the depth cue information. However, if depth cues effect is not revealed in Experiment 2, it means factors other than object detail might cause the disappearance of depth cues effect. For instance, object number might also affect infants' visual explorations. In Guan & Corbetta's (2012) study, there were 3 objects on each slide. However, in the present study there are only 2 objects on each slide. Two objects might have introduced stronger size contrast between the two objects than three objects thus overpowering the effect of depth cues.

Chapter 3 Experiment 2

The main purpose of Experiment 2 was to determine if adding details to the objects in Experiment 1 caused the disappearance of the main depth cues effect. Thus, details were removed from each slide to test infants' visual responses by using the same procedure in Experiment 1.

3.1 Method

3.1.1 Participants

Twenty infants were used for Experiment 2, including ten 5-month-old (±1 week) infants and ten 8-month-old (±1 week) non-crawlers. There were an equal number of males and females within each group. The subject recruitment followed the same method as in Experiment 1. An additional two infants were brought to the laboratory but were excluded from the analyses due to fussiness. Among the sample that yielded useable data, 19 participants were Caucasian and one was African American. All parents consented to have their infants participate in this study, and they received a photo and certificate of their participation.

3.1.2 Material

Same materials were used in this experiment as in Experiment 1.

3.1.3 Design of stimuli

There were no details on either object in this experiment, which is the only difference in the design of stimuli compared to Experiment1.

3.1.4 Procedure

The procedure in this experiment followed the same steps as in Experiment 1.

3.1.5 Analyses

3.1.5.1 First look

The first object visually attended to

Similar to Experiment 1, Tobii Studio outputs a table of the first fixation, which identifies the first object infants visually fixated on. Thus, using this table, I was able to determine which object caught infants' attention first when each slide was presented.

Latencies to the two objects

Tobii studio also exported the latency to each object in the scene. As in Experiment 1, the latency was defined as the time elapsed between the beginning of the slide presentation and the visual shift to each object in Experiment 2.

3.1.5.2 Sustained attention

Look durations to each object were also measured in Experiment 2. To keep the analysis consistent with Experiment 1, infants' sustained attention to the two objects in the scene were compared within the three different-size conditions and three same-size conditions by depth cues and age groups.

3.1.6 Criterion for selection of useable data

Criterion for data selection was the same as in Experiment 1. Based on the 3-second rule, 89.44% of trials (range from 72.22% to 100%, median 91.67%) were used for 5 months old subjects and 94.44% of trials (ranged from 83.33% to 100%, median 100%) were used for 8 months old subjects. No subject had more than 50% of the slides below the 3-second criteria so that all the subjects were kept in this experiment.

3.2 Results

3.2.1 First look

The first object visually attended

Objects of different sizes

Since the data was not normally distributed based on the normality test ($P = 0.032$, skewness = 1.78, kurtosis = -0.17), non-parametric Wilcoxon tests were used to determine whether one object on the slide caught infants' attention more frequently than the other in Experiment 2. The results showed again that infants in both age groups tended to shift their gaze significantly first to the large object in all the different-size conditions regardless of depth cue information (congruent: 8 months: $Z = -5.11$, $P = 0.0001$; 5 months: $Z= -3.66$, $P = 0.0001$; reversed: 8 months: $Z = -4.56$, $P = .0001$; 5 months: $Z = -2.34$, $P = .02$; no depth: 8 months: $Z = -3.40$, $P = 0.001$; 5 months: $Z = -2.35$, $P = 0.02$). Figure A15 indicates the patterns of first directed attention to one of the two objects on the slides were scaled as a function of the sizes of the objects for the two age groups. Based on these results, it shows that infants in both age groups tended to shift their gaze first to the large object in all the different-size conditions regardless of background depth cues.

Objects of same size

Since the data was also not normally distributed based on the normality test ($p = 0.002$, skewness = 0.53, kurtosis = -1.21), non-parametric Wilcoxon tests were used to determine whether top or bottom object on the slide caught infants' attention more frequently than the other. The results showed that when the two objects were of the same size, 5-month-old infants tended to first look at the bottom object (0° condition: $Z = -3.05$,

P = 0.05; 180° condition: Z = -3.75, P = 0.002; no depth cues condition: Z = -3.25, P = 0.03). While 8-month-old infants did not show any first look preference in all the conditions. Figure A16 displays patterns of the first directed attention to one of the two objects on the slide in the same-size conditions. Based on these results, it shows that when the two objects were of the same size, 8-month-old infants did not show first look preferences to the top or bottom object while 5-month-old infants showed bottom preference of their first look.

Latency to the two objects

Objects of different sizes

As in Experiment 1, this measure captured the time elapsed between the beginning of the slide presentations and the visual shift to the two objects in the scene in all different-size conditions. Since the data was normally distributed, a univariate GLM with latency as a dependent variable was used to test if displays had effects on infants' first look. The univariate GLM contained the following fixed factors: age (5- & 8-month-olds), depth conditions (congruent, reversed, and no depth cues), depth orientations (0°, 180°), and displays (vertical, diagonal to the left, diagonal to the right). No effects of displays were present in this data. Thus, repeated measures GLMs were used to test the effects of other factors after combining all the three displays. When sphericity assumptions were not met, P values provided by the Greenhouse-Geisser or Huynh-Feldt corrections were used, depending on the Epsilon value.

Results of repeated measures GLMs only showed a main effect of size ($F(1, 18) = 59.00$, $p = 0.0001$, $\eta_p^2 = 0.62$). Figure A17, displays these results and shows that infants

in both age groups proportionally shifted their attention to the large object faster than to the small object (large: M = 761.24 ms; small: M = 1653.21 ms).

Objects of same size

As in Experiment 1, this measure captured the time elapsed between the beginnings of the slide presentation and the visual shift to the two objects in the scene in all same-size conditions. Since the data was normally distributed, a univariate GLM with latency as a dependent variable was used to test if displays had effects on infants' latency. The univariate GLM contained the following fixed factors: age (5- & 8-month-olds), depth conditions (0°, 180°, no depth cues), and displays (vertical, diagonal to the left, diagonal to the right). No effects of displays were present in this data. Thus, repeated measures GLMs were used to test the effects of other factors after combining all the three displays. When sphericity assumptions were not met, P values provided by the Greenhouse-Geisser or Huynh-Feldt corrections were used, depending on the Epsilon value.

Results of repeated measures GLMs showed no effects of depth ($F(1, 18) = 59.00$, $p = 0.53$, $\eta_p^2 = 0.21$), location ($F(1, 18) = 73.25$, $p = 0.65$, $\eta_p^2 = 0.64$), or age ($F(1, 18) = 49.70$, $p = 0.09$, $\eta_p^2 = 0.11$). All infants directed their first look to either the top or the bottom object in the scene randomly (top: M = 973.23 ms; bottom: 1057.87 ms).

3.2.2 Sustained attention

Objects of different sizes

The looking duration on the large and small objects were compared within Experiment 2. First, a univariate GLM was used with the same set up as in Experiment 1, omitting detail as a factor, to test display effects: looking time as a dependent variable,

three depth cues conditions (congruent, reversed, no depth cues), two orientations (0^{o}, 180^{o}), three displays (vertical, diagonal to the left, diagonal to the right), two object sizes (small, large) and two age groups (5 months, 8 months) as fixed factors. No display effects were found in this data. Thus, the repeated measures GLM were used to test the effects of other factors after combining the three displays together.

As figure A18 displays, the repeated measures GLM results of Experiment 2 still suggested a main effect of size ($F(1, 26) = 243.11$, $p = 0.0001$, $\eta_p^2 = 0.23$) but no effects of depth cues. Infants looked longer at the large object than the small object on average, irrespective of depth cues. As shown in figure A19, an orientation by size interaction ($F(1, 26) = 9.23$, $p = 0.003$, $\eta_p^2 = 0.25$) was revealed in this analysis, similar to the results of Experiment 1. A follow-up ANOVA demonstrated that infants looked longer at the large object in the 0° orientation condition than in the 180° orientation condition ($t(19) = 35.24$, $p = 0.02$, $\eta_p^2 = 0.10$).

Objects of same size

Infants' looking duration to the top and bottom objects were compared within all the same-size stimuli. A GLM univariate with looking time as dependent variable, two depth conditions (depth cues, no depth cues), two orientations (0^{o}, 180^{o}), two detail conditions (details on the top object [DT], details on the bottom object [DB]), three displays (vertical, diagonal to the left, diagonal to the right), two object locations (top, bottom) and two age groups (5 months, 8 months) as fixed factors was conducted. The results revealed no display effects again. Thus, the repeated measures GLM were used after combining the three displays to test the effects of other factors.

Results of repeated measures GLM showed a main effect of location ($F(1, 38) = 11.72$, $p = 0.0001$, $\eta_p^2 = 0.24$). As figure A20 shows, infants showed a preference for the bottom object.

3.3 Experiment 2 Summary

The looking duration results in Experiment 2 showed that there was no effect of depth cues, which suggests that adding details to the objects likely did not drive the lack of depth cues effect in Experiment 1. Thus, changing object number from 3 to 2 in this study might have introduced stronger size contrasts between the two objects, thus overpowering the depth cue effect.

Chapter 4 Discussion

The development of infant visual attention on 2D displays has been studied for several decades and remains an important area of study in understanding many perspectives of early development, especially how information processing happens during the first year of life. Since 1970s, theoretical approaches aimed at understanding the process of infants' visual perception have set up the groundwork suggesting that infant visual attention is a multiple-component process which involves at least two parts: the attention-getting and attention-holding processes (Cohen, 1972). More recent studies further developed this idea by combining psychophysiological methods into behavioral studies and have provided evidence that attention is not a unitary process (Colombo, 2001a; Colombo & Cheatham, 2006). Among several attentional processes, attention-getting can be explained by visuospatial orienting response which is a process that requires little information processing (Posner, Inhoff, Friedrich, & Cohen, 1987). This process can be measured by first look and latency to the first look. On the other hand, attention-holding can be correlated with sustained attention and lower heart rate, indicating active information processing (Fisk & Schneider, 1981; Lansink & Richards, 1997). This process can be measured by looking duration. As a result, several components of visual behaviors such as first look and looking durations should be measured separately in order to understand the underlying mechanisms of infants' visual information processing of 2D displays.

Based on contemporary frameworks of development of infant visual attention, we have pieces of information about how infants visually respond to object size, depths cues, and object detail separately and how these responses change with time. Previous work

has demonstrated that object size has an attention-getting property which can catch infants' initial visuospatial orienting responses quickly (e.g. Cohen, 1972). Depth cue information in the background can interact with object size to hold infants' sustained attention on the large object in the scene between 4 and 8 months of age (Guan & Corbetta, in prep). Also, infants' ability to process more detailed information increases with age (e.g. Dember & Earl, 1970; Brennan et al., 1966; Greenberg & O'Donnell, 1972; Greenberg & Weizmann, 1971). However, how infants process information in complex scenes with object size, depth cues, and object detail combined together and how this process develops during the first year of life is still an open question. However, dynamic systems theory suggests that visual development can be multi-causal and context dependent. Perceptual behavior is the result of both external factors (e.g. stimuli information) and internal factors (e.g. the maturation of the visual system). When the context/factors are changed, infants' looking patterns might be changed. Thus, the aim of the current study was to explore the relative impact of object size, depth cues, and object detail on infants' visual exploration by using a dynamic systems approach within a developmental framework. To address the question of this study, 5- and 8-month-old infants were presented with 2D displays with object size, depth cues, and object detail. Based on the idea that infant visual attention should be measured in a multi-component manner, I used eye-tracking methodology to investigate two visual processes: the first look (measurement of visuospatial orienting response) and look duration (measurement of sustained attention), in order to understand how each aspect of visual information processing is affected by these factors and how infants' visual exploration behaviors change over time during the first year of life.

To address the questions proposed in this study, I examined infants' visual responses to 2D slides with combined information of object size, depth cues, and object detail. Results suggested that object size is very influential in catching infants' attention. Specifically, infants' first visual responses were directed to the large object despite object detail and depth cue information. Infants also shifted their attention faster toward the large object in the scene. These results were consistent with prior studies providing evidence showing that object size has strong attention-getting property (Cohen, 1972; Newman et al., 2001, Guan & Corbetta, 2012). The magnocellular pathway is most responsive to the size information (Goodale & Milner, 2004). Compared to object detail and background depth cues, object size is the most salient factor for catching infant attention. The results from this study extend our understanding of the attention-getting process. Because most of the previous studies mainly examined object size alone or combine object size with another factor such as object number (e.g. Fanz, 1965; Cohen, 1972), whether object size still has the highest priority to catch infants' first visual attention under more complex conditions is still unknown. As infants are living in a very rich visual world and need to be able to simultaneously process object size, depth cues, and object detail, it is useful to study their visual exploration behaviors with all these factors combined in one scene. Thus, this study proposed a hierarchical model of object size, object detail, and depth cues on infants' attention-getting process. To elaborate, object size has the highest priority to attract infants' attention regardless of details and depth cue information. When objects are same size, object details become a salient factor in attracting infants' first visual attention. Depth cues, which does not show any effect in the attention-getting process, might not be salient enough to attract infants' attention

when compared to size and detail information. If we look at infants' visual responses to these three factors during the first year of life, it clearly shows that newborns already show strong responses to large, salient objects (Fantz, 1965; Salapatek, 1975; Bronson, 1990). They also show preferences for more detailed objects over simple objects and an increased ability to process more detailed information during the first half year of life (Fantz, Fagan, & Miranda, 1975; Fantz & Nevis, 1967). However, infants are not sensitive to pictorial depth cues until 4 months or older (Yonas et al., 2002; Durand et al., 2003), which means that processing pictorial depth cues is not an innate ability. Using depth cue information is a higher level, knowledge based ability which requires more information processing. Thus, this study has shown that object size has the greatest priority over object detail and depth cues on their attention-getting properties in infants.

In addition to the attention-getting function, object size also had the highest priority for holding infants' sustained attention in the current study. In both experiments, infants showed strong preferences for the large object in the scene irrespective of the details and depth cue information. The high size contrasts between the two objects in the scene may have made the large object appear more salient, thereby overpowering other information on the slide.

Although object size had the highest priority in both attention-getting and attention-holding process, object detail also showed several notable functions for impacting infants' visual exploration behaviors such as first look and sustained attention. First, in this study, details were able to get infants' attention initially when objects were of the same size. These results suggested that details functioned during early visuo-spatial orienting response, but this happened only when object sizes were the same. In addition,

details were also able to facilitate infants' first visual orienting response. Specifically, infants directed their first attention to the more detailed object faster than to the non-detailed object. While adding details to the small object slowed down infants' visual shifting to the large, non-detailed object in the scene. Second, details interacted with object size to manipulate infant visual attention during the attention-holding process. For instance, details on the large object can increase the saliency of the object to hold infants' attention. It is interesting to note that during the initial orienting response infants first directed their visual attention to the large object regardless of detail information. But when the details were added to the objects, they interacted with object size information later when infants were actively processing the information instead of early visuo-spatial orienting response. During this long information processing period, infants were able to combine the size and detail information in the scene so that the large, detailed object held their sustained attention longer than small or/and objects that lacked detail. Object detail, as we expected, was able to interact with the size information so as to increase or decrease the power of object size to hold infants' attention.

In addition to the influence that detail had on infants' first look and sustained attention, adding details to one of the objects in the scene in this study reduced infants' scanning rate based on the follow-up analysis by comparing the scanning rates in the two experiments. Scanning rate was defined as the number of fixation shifts per second in this study. The results showed that infants tended to perform more visual shifts per second between the two objects when neither object had details than in the scenes when one of the objects had details on it. This result was consistent with the expectation suggesting that adding detail to one object might cause a strong imbalanced in the amount of

information between the two objects. Thus, the detailed object had more power to hold infants' sustained attention thus reducing their visual scanning and comparison between the two objects. Keeping long sustained attention on the detailed object might be an efficient way to process more information in a limited visual exploration time. But when neither object had details, each object had the same power to hold infants' sustained attention so that infants looked back and forth to compare and explore the two objects.

In sum, for attention-getting, even though details had lower priority than object size to catch infants' attention, they became salient when object sizes were the same. For attention-holding, details were able to interact with size information to increase or decrease infants' sustained attention. Adding details to one object also reduced infants' scanning rate between the two objects, suggesting that infants' scanning behavior might also be an important feature to be examined in future visual attention studies.

Compared to object size and details, depth cue information might have the lowest priority in the attention-getting process according to the findings of this study. In both experiments, infants tended to first direct their attention to the large object (different-size conditions) or the more detailed object (same-size conditions). The results were consistent with my hierarchy hypothesis indicating that background depth cues were not as salient as size and detail information in the scene. Processing depth cue information requires longer time to combine the figure and ground information together. Even in the conditions when objects were of the same size and no details were present on both objects, infants still did not respond to depth cues when they first looked at the slide because they did not have enough time to process the depth information immediately. Based on Cohen's IPP theory, adding details to the objects might overload infant's visual

system so that infants only process lower level information such as object size and detail in this study (Cohen, Chaput, & Cashon, 2002). Another possibility of no depth cues effect might be because depth cues were not strong enough in this study. But this also brings up interesting questions: will adults be good enough to process the depth cue information even the cues are not very strong? Future studies are needed to explore this question.

In the attention-holding process, depth cues again did not show any main effects on infants' sustained attention in this study. These results were somewhat surprising given prior studies. According to Guan & Corbetta (2012), when there were only object size and depth cues in the scene, depth cues and object size both played an important role in holding infants' sustained attention on the largest object. Specifically, sustained attention to the largest object happened only when there were depth cues in the background. When the background depth cues were removed, infants no longer showed longer looking duration to the largest object. That means infants were able to integrate the depth information in the background and combine this information with size information. Why did the depth cues effect disappear in this study? One possible explanation might be because there were more different-size conditions used in this study than in Guan & Corbetta (2012). However, analyses test the conditions the same as Guan & Corbetta (2012) study after removing the extra conditions in this study suggested this was not the reason. Another possibility may be that adding the details on the objects overpowered the effect of depth cues. However, after conducting Experiment 2 in which all of the internal details on the objects were removed, the effect of depth cues observed in Guan & Corbetta (2012) study was still not found. After eliminating the former two

possibilities, one remaining possibility is that the change of object number from three to two in the current study might increase the size contrast of the two objects in the scene. In the prior study, three objects were scaled gradually with depth cues in the background with low size contrast. However, this current study only had two objects with high size contrast so that the large object could have appeared more salient and powerful to hold infant visual attention on that object regardless of depth cues. This suggests that future studies are needed to further understand the role of size, number, and depth cues on infants' visual processing. For example, will infants respond to depth cues if we reduce the size contrast between the two objects in this study? Or if we keep the same size contrast, will depth cue effects appear when we add more objects to the scene? What is the relationship between size contrasts and object number and their influences on the perception of pictorial depth cues? By exploring these questions, we can obtain a better understanding of the mechanisms of information processing on 2D displays.

Although different types of depth cues (congruent, reversed, no depth cues) did not affect infants' sustained attention in this study, an interesting result showed that infants were sensitive to depth cue orientation. Specifically, in both experiments, all infants responded more to the large object in the 0° orientation than in the 180° orientation. This result might tell us that infants are more sensitive to the upright scene that they usually see in the natural environment than the up-side-down scene, an idea which is supported by several fMRI studies on adults suggesting that rotating an identical object could elicit a greater fMRI response (Malach, Reppas, Benson, Kwong, Jiang, Kenneday, Ledden, Brady, Rosen, & Tootell, 1995; Murray & Wojciulik, 2004). Thus, infants' visual responses to scenes with different orientations might activate different

parts of the brain which control the looking durations on the objects when they are at different orientations.

Looking at the current study from a developmental perspective, older infants showed more sensitivity to object detail and more numbers of visual shifts per second than did younger infants. These results might be due to physical maturation of the visual system during the first year. The fast development of the visual system might improve infants' visual scanning speed and visual flexibility so that older infants can shift their attention faster. For the attention-holding process, it seems that size had strong power to hold infants' attention in both age groups. When objects were of the same size, infants showed preferences to the bottom object. The bottom preferences were also found in the Guan & Corbetta (2012) study, which might be because it was easier to sustain attention to the lower object when the two objects had the same amount of information. However, even though infants preferred to look at the bottom object, 8-month-old infants shifted their attention more to the top object when details were added so that details were able to change their bottom preference. Five-month-old infants did not have as strong of a response to the details as 8-month-old infants. Older infants' higher sensitivity to details might be due to their increased peripheral visual field. This finding is supported by the Farzin et al (2010) work showing that infants' peripheral vision increases with age. Also, the results might reflect that infants' processing capacity to details grows with age, consistent with prior studies (e.g. Dember & Earl, 1970; Brennan et al., 1966; Greenberg & O'Donnell, 1972). Thus, the current study provides evidence that internal factors such as physical maturation cannot be ignored when studying infant visual attention.

In sum, the results of the current study provided evidence that infants' visual behavior is a dynamic process, which can be affected by changing external stimuli. Even though size had a strong effect on infants' attention-getting and attention-holding processes, it interacted somewhat with details and depth cue information, such that adding new information to the scene changed infants' visual responses. This study is consistent with prior work on infant visual attention suggesting that attention should be studied via multiple components (e.g. Colombo, Kapa, and Curtindale, 2011; Richards, 2012). Measuring the first look (the measurement of visuospatial orienting response) and looking duration (the measurement of sustained attention) are both important aspects in studying infants' visual exploration patterns.

Study limitations

One limitation of the current study has to do with the design of the stimuli slides. Since there were only two objects in the scene, the size contrast was so strong that it may have prevented us from seeing any effects of depth cues. Thus, additional research with slides with three objects, or two objects with reduced size contrast, with gradually changing pictorial depth cues is needed to further study the effects of depth cues under the context with object size and details. However, despite the fact that the current study used two objects instead of three, the stronger attention-getting and attention-holding effects of object size were found in the results, indicating that increasing an object's saliency might increase its power to get and hold infants' attention. Also the interaction of object size and details was found in the sustained attention results, suggesting details were interacting with object size to affect infants' visual explorations. Moreover, we obtained a better understanding of how dynamic infant perception is and how important

the stimulus characteristics are. Even slightly changing the stimuli, such as object number, can alter infants' visual behaviors dramatically.

Concluding remarks

The results of the current study may be sufficiently explained by the combination of dynamic systems theory (Thelen & Smith, 2006), attention-getting and attention-holding theory (Cohen, 1972), and complexity theory (e.g. Dember & Earl, 1970; Brennan et al., 1966; Greenberg & O'Donnell, 1972; Karmel & Maisel, 1975). For instance, infants first tend to look at the large object in the scene. However, when the size was the same, details became the priority factor to catch infants' first attention. Introducing details to the object might change infants' visual exploration behaviors. These results provided evidence that changing external stimuli can affect infants' initial orienting responses, suggesting that infants' visual behavior is a dynamic process. Similarly, infants' sustained attention was affected by the interactions between object size, depth cues, and object detail. Theoretically, infants' visual exploration behaviors are context dependent and can be affected by multiple factors. Adding details to object size and depth cues in the 2D displays will change infants' looking patterns. All three of these factors interact with each other so that to manipulate infants' visual exploration behaviors. Overall, this study provides support for the dynamic systems theory suggesting that perception can be affected by external factors. Changing environmental factors such as manipulating the details in the scene might also change infants' looking patterns.

Looking at this study from a developmental perspective, older infants showed more sensitivity to object detail than did younger infants. These results might be due to physical maturation of the visual system during the first year. The fast development of

the visual system might improve infants' sensitivity to detail. Thus, the current study provides evidence that internal factors such as physical maturation cannot be ignored to study infant visual attention.

Above all, both internal and external factors should be considered when studying infants' visual preference and development. Both of these factors play important roles and neither of them can be ignored. Combining dynamic systems theory with information processing theory allows for an explanation of visual attention in a more holistic and context dependent way. Also, this study highlights how amazing it is that such young human infants already have competent visual abilities. Programming a machine to perceive like a human is challenging (Arel & Barrant, 2010). According to a phenomenon called "curse of dimensionality", adding input variables can increase the complexity of training a system to recognize patterns potentially. But human infants, especially toward the end of the first year, appear to do the job of grasping the major information in the scene easily and efficiently (Farzin, Rivera, & Whitney, 2010). Thus, understanding how infants cope with complex information may provide some ideas for computational perception models. Further studies are still needed to explore how multiple factors affect infants' visual exploration from developmental perspectives.

List of References

Amso, D., & Johnson, S. P. (2006). Learning by selection: Visual search and object perception in young infants. *Developmental Psychology*, *42*, 1236–1245.

Arela, I., & Berantb, S. (2010). Application Feedback in Guiding a Deep-Layered Perception Model. In Biologically Inspired Cognitive Architectures 2010: Proceedings of the First Annual Meeting of the BICA Society (Vol. 221, p. 4). IOS Press, Incorporated.

Aslin, R. N. (1987). Visual and auditory development in infancy. In J. D. Osofsky (Ed.), *Handbook of infant development* (2nd ed., pp. 5-97). New York: Wiley.

Baillargeon, R. (1987b). Object permanence in 3.5- and 4.5-month-old infants. *Developmental Psychology, 23,* 655-664.

Ball, W.A., & Vurpillot, E. (1976). Perception of movement in depth in infants. *Annual Psychology*. *76(2),* 383-99.

Baluja, S., & Fahlman, S. E. (1994). *Reducing network depth in the cascade-correlation learning architecture.* Technical Report CMU-CS-94-209, Carnegie Mellon University.

Banks, M.S., & Ginsburg, A.P. (1985). Early visual preferences: A review and new theoretical treatment. In H.W. Reese (Ed.), *Advances in child development and behavior* (Vol. 19). New York: Academic.

Banks, M. S., & Salapatek, P. (1981). Infant pattern vision: A new approach based on the contrast sensitivity function. *Journal of Experimental Child Psychology, 31,* 1-45.

Bellman, R. (1957). *Dynamic Programming*, Princeton University Press.

Bertenthal, B. I., Campos, J. J., & Kermoian, R. (1994). An epigenetic perspective on the development of self-produced locomotion and its consequences. *Current Directions in Psychological Science*, *3*, 140–145.

Bonds, A. B. (1979). Development of orientation tuning in the visual cortex of kittens. In R. D. Freeman (Ed.), *Developmental neurobiology of vision*, New York: Plenum.

Bower, T. R. (1965). Stimulus variables determining space perception in infants. *Science*, *149*, 88-89.

Brennan, W. M., Ames, E. W., & Moore, R. W. (1966). Age differences in infants' attention to patterns of different complexity. *Science*, *151*, 354-356.

Bronson, G. W. (1990). Changes in infants' visual scanning across the 2- to 14-week age period. *Journal of Experimental Child Psychology*, *49*, 101–25.

Bushnell, E. W., & Boudreau, J. P. (1991). The development of haptic perception during infancy. In M. A. Heller & W. Schiff (Eds.), *The psychology of touch* (pp. 139-161). Hillsdale, NJ: Erlbaum.

Chaput, H. H. (2004). *The Constructivist Learning Architecture: A Model of Cognitive Development for Robust Autonomous Robots.* Doctoral dissertation, Computer Science Department, University of Texas at Austin.

Chiel, H. J., & Beer, R. D. (1997). The brain has a body: adaptive behavior emerges from interactions of nervous system, body and environment. *Trends in Neuroscience*, *20*, 553-557.

Chugani, H. T. (1994). Development of regional brain glucose metabolism in relation to behavior and plasticity. In: Dawson G, Fischer KW, editors. *Human behavior and the developing brain*, New York, NY: Guildford, 153–75.

Cohen, L. B. (1972). Attention-getting and attention-holding processes of infant visual preferences. *Child Development*, *43*, 869-879.

Cohen, L. B., Chaput, H. H., & Cashon, C. H. (2002). A constructivist model of infant cognition. *Cognitive Development*, *17*, 1323–1343.

Cohen, L. B., & Younger, B. A. (1984). Infant perception of angular relations. *Infant Behavior and Development*, *7*, 37-47.

Colombo, J. (2001a). The development of visual attention in infancy. *Annual review of Psychology*, *52*, 337-367.

Colombo, J., & Cheatham, C. (2006). The emergence of endogenous attention in infancy and early childhood. In R. Kail (Ed.), Advances in child development and behavior (pp. 283-322). New York: Elsevier.

Corbetta, D., Guan, Y., & Williams, J. L. (2012). Infant Eye Tracking in the Context of Goal Directed Actions. *Infancy*, *17(1)*, 102-125.

Courage, M. L., Reynolds, G. D., & Richards, J. E. (2006). Infant visual attention to patterned stimuli: Developmental change from 3- to 12-months of age. *Child Development*, **77**, 680–695.

Dember, W. N., & Earl, R. W. (1957). Analysis of exploratory, manipulatory, and curiosity behaviors. *Psychological Review*, *64*, 91-96.

Deregowski, J. B. (1969). Perception of the two-pronged trident by two- and three-dimensional perceivers. *Journal of Experimental Psychology*, 82, 9-13.

Durand, K., Lecuyer, R., & Frichtel, M. (2003). Representation of the third dimension: The use of perspective cues by 3- and 4-month-old infants. *Infant Behavior and Development*, *26*, 151 – 166.

Fantz, R. L. (1963). Pattern vision in newborn infants. *Science, 140,* 296-297.

Fantz, R. L. (1965). Visual perception from birth as shown by pattern selectivity. In H. E. Whipple (Ed.), *Annals of the New York Academy of Sciences: Vol. 118. New issues in infant development* (pp. 792-814). New York: New York Academy of Sciences.

Fantz, R. L., Fagan, J. F., III, & Miranda, S. B. (1975). Early visual selectivity as a function of pattern variables, previous exposure, age from birth and conception, and expected cognitive deficit. In L. B. Cohen & P. Salapatec (Eds.), *Infant perception: From sensation to cognition. Basic visual processes* (Vol. 1). New York: Academic Press.

Fantz, R. L., & Nevis, S. (1967). Pattern preferences and perceptual-cognitive development in early infancy. *Merrill-Palmer Quarterly, 13,* 77-108.

Farzin, F., Rivera, S. M., & Whitney, D. (2010). Spatial resolution of conscious visual perception in infants. *Psychological science, 21(10),* 1502-1509.

Fisk, A. D., & Schneider, W. (1981). Control and automatic processing during tasks requiring sustained attention: A new approach to vigilance. *Human Factors, 23(6),* 737–750.

Fraiberg, S., Smith, M., & Adelson, E. (1969). An educational program for blind infants. *Journal of Special Education, 3(2),* 121-139.

Garey, L. J., & De Courten, C. (1983). Structural development of the lateral geniculate nucleus and visual cortex in monkey and man. *Behavioral Brain Research, 10,* 3–13.

Gibson, J. (1977). *The theory of affordances*. In R. E. Shaw and J. Bransford, eds., Perceiving, Acting, and Knowing, Hillsdale: Lawrence Erlbaum Assoc.

Gibson, E. J., & Walk, R. D. (1960). The "visual cliff." *Scientific American, 202* ,64-71.

Goodale, M., & Milner, D. (2004). *Sight unseen.* Oxford University Press, Inc.: New York.

Gottlieb, G. (2009). Environmental and Behavioral Influences on Gene Activity. In L. S. Liben (Ed.), *Current Directions in Developmental Psychology* (pp. 93-97). Boston: Pearson.

Gottlieb, G., Wahlsten, Lickliter. (2006). The Significance of Biology for Human Development: A Developmental Psychobiological Systems View. In R. M. Lerner (Ed.), *Handbook of Child Psychology. Vol. 1: Theoretical models of human development* (5th ed., pp. 233-273). New York: John Wiley & Sons, Inc.

Graham, F. K. (1970). Cardiac orienting responses as a function of age. *Psychonomic Science*, 19, 363-365.

Graham, F. K. (1979). Distinguishing among orienting, defense, and startle reflexes. In H. D. Kimmel, E H. van Olst, & J. F. Orlebeke (Eds.), *The orienting reflex in humans* (pp. 137-167). Hillsdale, NJ: Erlbaum.

Graham, F. K. (1992). Attention: The heartbeat, the blink, and the brain. In B. A. Campbell, H. Hayne, & R. Richardson (Eds.), *Attention and information processing in infants and adults* (pp. 3-29). Hillsdale, NJ: Lawrence Erlbaum.

Granrud, C. E., Yonas, A., & Opland, E. A. (1985). Infants’ sensitivity to the depth cue of shading. *Perception and Psychophysics, 37*, 415–419.

Granrud, C. E., Yonas, A., Forsyth, K. K., & Le, M. L., (2007). *Pictorial size constancy in 4- to 7-month-old infants.* Poster presented at the Biennial Meeting of the Society for Research in Child Development, Boston, MA.

Greenberg, D. J., & O'Donnell, W. J. (1972). Infancy and the optimal level of stimulation. *Child Development*, *43*, 639-645.

Greenberg, D. J., Weizmann, F. (1971). The measurement of visual attention in infants: a comparison of two methodologies. J. *Experimental Child Psychology, 11*, 234–43.

Greenough, W., Black, J., & Wallace, C. (1987). Experience and brain development. *Child Development*, *58*, 539-559.

Guan, Y., & Corbetta, D. (2012). What grasps and holds 8-month-old infants' looking attention? The effects of object size and depth cues. *Child Development Research.* doi:10.1155/2012/439618

Hainline, L., Turkel, J., Abramov, I., Lemeris, E., Harris, C. M. (1985). Characteristics of saccades in human infants. *Vision Research*, *24*, 1771-80.

Haith, M. M. (1978). Visual competence in early infancy. In R. Held, H. Leibowitz, & H. L. Tenber (Eds.), *Handbook of sensory physiology*, Berlin: S;pringer-Verlag.

Holway, A. H., & Boring, E. G. (1941). Determinants of apparent visual size with distance variant. *The American Journal of Psychology*, *54*, 21-37.

Hood, B. M. (1995). Shifts of visual attention in the infant: a neuroscientific approach. *Advances in Infancy Research*, *9*, 163–216.

Hull, J. C., Gill, R.T., & Roscoe, S. N. (1982). Locus of the Stimulus to Visual Accommodation: Where in the World, or Where in the Eye? *Human Factors: The Journal of the Human Factors and Ergonomics Society, 24 (3),* 311-319(9).

Humphrey, G. (1924). The psychology of the gestalt. *Journal of Educational Psychology, 15(7),* 401–412.

Iavecchia, J. H., Iavecchia, H. P., & Roscoe, S. N. (1983). The moon illusion revisited. *Aviation, Space, and Environmental Medicine, 54,* 39-46.

Kavsek, M., Yonas, A., & Granrud, C. E. (2011). *Infants' sensitivity to pictorial depth cues: A review and meta-analysis of looking studies. Infants Behavior and Development, 35*, 109-128.

Karmel, B. Z., & Maisel, E. B. (1975). A neuronal activity model for infant visual attention. In L. B. Cohen & P. Salapatek (Eds.), *Infant perception: From sensation to cognition. Basic visual processes* (Vol. 1). New York: Academic Press.

Kellman, P. J., & Spelke, E. S. *(1983). Perception of partly occluded objects in infancy. Cognitive Psychology, 15,* 483-524.

Kuo, Z. Y. (1970). The need for coordinated efforts in developmental studies. In L. R. Aronson, E. Tobach, D. S. Lehrman, & J. S. Rosenblatt (Eds.), *Development and evolution of behavior: Essays in memory of T. C. Schneirla* (pp. 181-193). San Francisco: Freeman.

Lansink, J. M, & Richards, J. E. (1997). Heart rate and behavioral measures of attention in 6-, 9-, and 12-month-old infants during toy play. *Child Development. 68*, 610–20.

Mainline, L., & Abramov, I. (1992). Assessing visual development: Is infant vision good enough? In C. K. Rovee-Collier & L. Lipsitt (Eds.), Advances in infancy research (pp. 39-102). Norwood, NJ: Ablex.

Malach, R., Reppas, J. B., Benson, R. R., Kwong, K. K., Jiang, H., Kennedy, W. A., Ledden, P. J., Brady, T. J., Rosen, B. R., & Tootell, R. B. (1995). Object related activity revealed by functional magnetic resonance imaging in human occipital cortex. *Proc. Natl. Acad. Sci. U.S.A. 92*, 8135–8139.

Meehan, J. W., &Triggs, T. J. (1988). Magnification effects with imaging displays depend on scene content and viewing condition. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *30,* 487-494.

Milner, A. D., & Goodale, M. A. (1993). Visual pathways to perception and action. *Progress in Brain Research, 95*, 317–337.

Milner, A. D., & Goodale, M. A. (2008). Two visual systems re-viewed. *Neuropsychologia*, *46(3)*, 774-785.

Miranda, S. B. (1970). Visual abilities and pattern preferences of premature infants and full-term neonates. *Journal of Experimental Child Psychology*, *10*, 189-205.

Munsinger, H., & Weir, M. W. (1967). Infants' and young children's preference for complexity. *Journal of Experimental Child Psychology*, *5*, 69-73.

Murray, S. O., and Wojciulik, E. (2004). Attention increases neural selectivity in the human lateral occipital complex. *Nat. Neurosci. 7*, 70–74.

Náñez, J.E., & Yonas, A. (1994). Effects of luminance and texture motion on infant defensive reactions to optical collision. *Infant Behavior and Development*. *17*, 165-174.

Newman, C., Atkinson, J., and Braddick, O. (2001). The development of reaching and looking preferences in infants to objects of different sizes. Developmental Psychology, Vol. 37, pp. 561-572, 2001.

Oakes, L. M, & Tellinghuisen, D. J. (1994). Examining in infancy: Does it reflect active processing? *Development Psychology, 30,* 748–56.

Piaget, J. (1953*). The origins of Intelligence in the Child*. London: Routledge and Kegan Paul.

Porges, S. W. (1976). Peripheral and neurochemical parallels of psychopathology: A psychophysiological model relating autonomic imbalance in hyperactivity, psychopathology, and autism. In H. Reese (Ed.), *Advances in child development and behavior* (pp. 35-65). New York: Academic Press.

Porges, S. W. (1980). Individual differences in attention: A possible physiological substrate. In B. Keogh (Ed.), *Advances in special education* (pp. 111-134). Greenwich, CT: JAI.

Posner, M. I. (1995). Attention in cognitive neuroscience: An overview. In M. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 615 – 624). Cambridge, MA: MIT Press.

Posner, M. I., Inhoff, A. W., Friedrich, F. J., & Cohen, A. (1987). Isolating attentional systems: A cognitive-anatomical analysis. *Psychobiology, 15,* 107–121.

Posner, M. I., & Peterson, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13*, 25-42.

Posner, M. I., & Rothbart, M. K. (2007). Research on attention networks as a model for the integration of psychological science. *Annual Review of Psychology, 58,* 1–23.

Quinn, P. C., & Eimas, P. D. (2000). The emergence Posner, M. I., & Keele, S. W. (1968). On the genesis of abstract ideas. *Journal of Experimental Psychology, 77,* 353-363.

Reynolds, G.D., Courage, M.L, & Richards, J.E. (in press). The development of attention. In D. Reisberg (Ed.), Oxford Handbook of Cognitive Psychology, Oxford University Press.

Richards, J. E. (1987). Infant visual sustained attention and respiratory sinus arrhythmia. *Child Development*, 58, 488-496.

Richards, J. E., & Casey, B. J. (1992). Development of sustained visual attention in the human infant. In B. A. Campbell, H. Hayne, & R. Richardson (Eds.*)*, *Attention and information processing in infants and adults (*pp. 30-60). Mahway, NJ: Erlbaum.

Rock, I., & Kaufman, L. (1962). The Moon Illusion, II: The moon's apparent size is a function of the presence or absence of terrain. *Science*. *136 (3521)*, 1023-1031.

Robbins, T. W., & Everitt, B. J. (1995). Arousal systems and attention. In M. S., Gazzaniga, (Ed.) *The cognitive neurosciences* (pp. 703-720). Cambridge, MA: The MIT Press.

Rueda, M. R., Posner, M. I., & Rothbart, M. K. (2005). The development of executive attention: contributions to the emergence of self-regulation. *Developmental Neuropsychology*, 28, 573-594.

Ruff, H. A., & Birch, H. G. (1974). Infant visual fixation: The effect of concentricity, curvilinearity, and number of directions. *Journal of Experimental Child Psychology*, *17*, 460-473.

Ruff, H. A., & Rothbart, M. K. (1996). *Attention in early development: Themes and variations*. New York: Oxford University Press.

Ruff, H. A., Saltarelli, L. M. (1993). Exploratory play with objects: Basic cognitive processes and individual differences. In M. H. Bornstein & A. W. O'Reilly (Eds), *New Directions for Child Development: Vol. 59. The role of play in the development of thought* (pp. 5-15). San Francisco, CA: Jossey-Bass.

Ruff, H. A., & Turkewitz, G. (1975). Developmental changes in the effectiveness of stimulus intensity on infant visual attention. *Perceptual and Motor Skills*, *48*, 815-826.

Salapatek, P. (1975). Pattern perception in early infancy. In L. Cohen & P. Salapatek (Eds.), *Infant perception: from sensation to cognition (Vol. 1). Basic visual processes*. New York: Academic Press.

Salapatek, P., & Kessen, W. (1966). Vision scanning of triangles by the human newborn. Journal of Experimental Child Psychology, *3*,155-167.

Schneirla, T. C. (1966). Behavioral development and comparative psychology. *Quarterly Review of Biology, 41*, 283-302.

Sereno, M. I., Dale, A. M., Reppas, J. B., Kwong, K. K., Belliveau, J. W., Brady, T. J., Rosen, B. R., and Tootell, R. B. H. (1995). Borders of multiple visual areas in humans revealed by functional magnetic resonance imaging. *Science, 268*, 889–893.

Thelen, E. (1985). Developmental origins of motor coordination: Leg movements in human infants. *Developmental Psychobiology*, *18*, 1-22.

Thelen, E. (1989). The (re) discovery of motor development: Learning new things from an old field. *Developmental Psychology, 25*, 946-949.

Thelen, E. (1992). Development as a dynamic system. *Current Directions in Psychological Science*, *1*, 189-193.

Thelen, E. (1994). Three-month-old infants can learn task-specific patterns of interlimb coordination. *Psychological Science, 5*, 280-285.

Thelen, E. (2000). Grounded in the world: Developmental origins of the embodied mind. *Infancy*, *1*, 3-28.

Thelen, E., & Corbetta, D. (1994). Exploration and selection in the early acquisition of skill. *International Review of Neurobiology, 37*, 75-102.

Thelen, E., & Corbetta, D. (2002). Microdevelopment and dynamic systems: Applications to infant motor development. In N. Granott & J. Parziale (Eds.), *Microdevelopment: Transition processes in development and learning* (pp. 80-108). New York: Cambridge University Press.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. Massachusetts: The MIT Press.

Thelen, E., & Smith, L. B. (2006). Dynamic systems theories. In R. M. Lerner (Ed.), *Handbook of child psychology, Vol. 1: Theoretical models of human development* (6th ed., pp. 258-312). New York, NY: John Wiley & Sons, Inc.

Titchener, E.B. (1921). Wilhelm Wundt. *The American Journal of Psychology, 32* .309-411.

Wertheimer, M. (1912). Experimentelle Stuidien uber das Sehen von Beuegung. *Zeitchrift fuer Psychologie, 62,* 161-*265.*

Wilcox, B. L., & Teghtsoonian, M. (1971). The control of relative size by pictorial depth cues in children and adults. *Journal of Experimental Child Psychology, 11(3),* 413-429.

Wolff, P. H. (1987*). The development of behavioral states and the expression of emotions in early infancy*. Chicage: Chicago University Press.

Yonas, A., Cleaves, W., & Pettersen, L. (1978). Development of sensitivity to pictorial depth. *Science, 200*, 77-79.

Yonas, A., Elieff, C. A., & Arterberry, M. E. (2002). Emergence of sensitivity to pictorial depth cues: Charting development in individual infants. *Infant Behavior and Development, 22*, 495-514.

Yonas, A., & Granrud, C. E. (2006). Infants' perception of depth from cast shadows. *Perception & Psychophysics, 68,* 154–160.

Yonas, A., Granrud, C. E.,&Pettersen, L. (1985). Infants' sensitivity to relative size information for distance. *Developmental Psychology, 21*, 161–167.

Yonas, A., Pettersen, L., & Granrud, C. E. (1982). Infants‟ sensitivity to familiar size as information for distance. *Child Development, 53*, 1285-1290.

Younger, B., & Cohen, L. B. (1986). Developmental change in infants' perception of correlations among attributes. *Child Development, 57*, 803–815. *Psychology, 15*, 483-524.

Appendix

Figure A 1: Experimental set-up showing the eye-tracker, the infant seat, and the white board presentation screen (same as Guan & Corbetta, 2012).

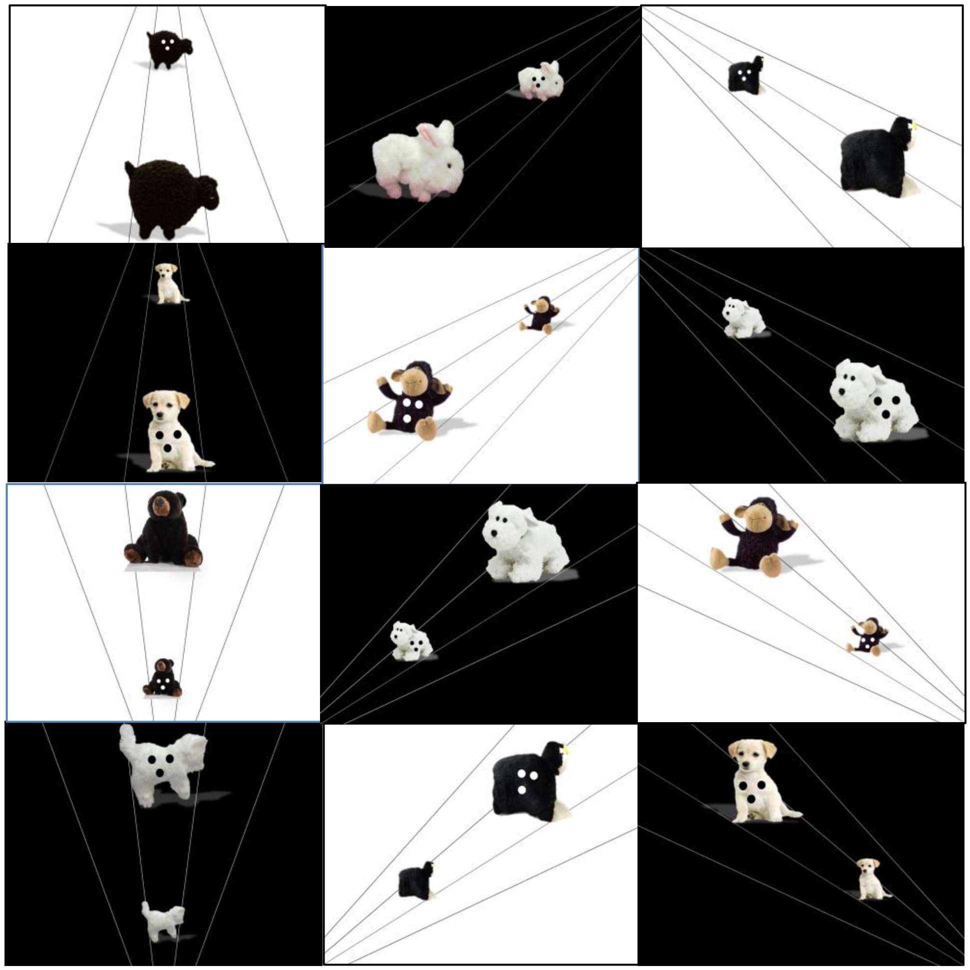

Figure A 2: Four rows different-size, congruent depth-cue conditions arranged in the order of: Con-0-DS, Con-0-DL, Con-180-DS, Con-180-DL by three columns arranged by the directions of depth cues: vertical, diagonal to the right, diagonal to the left.

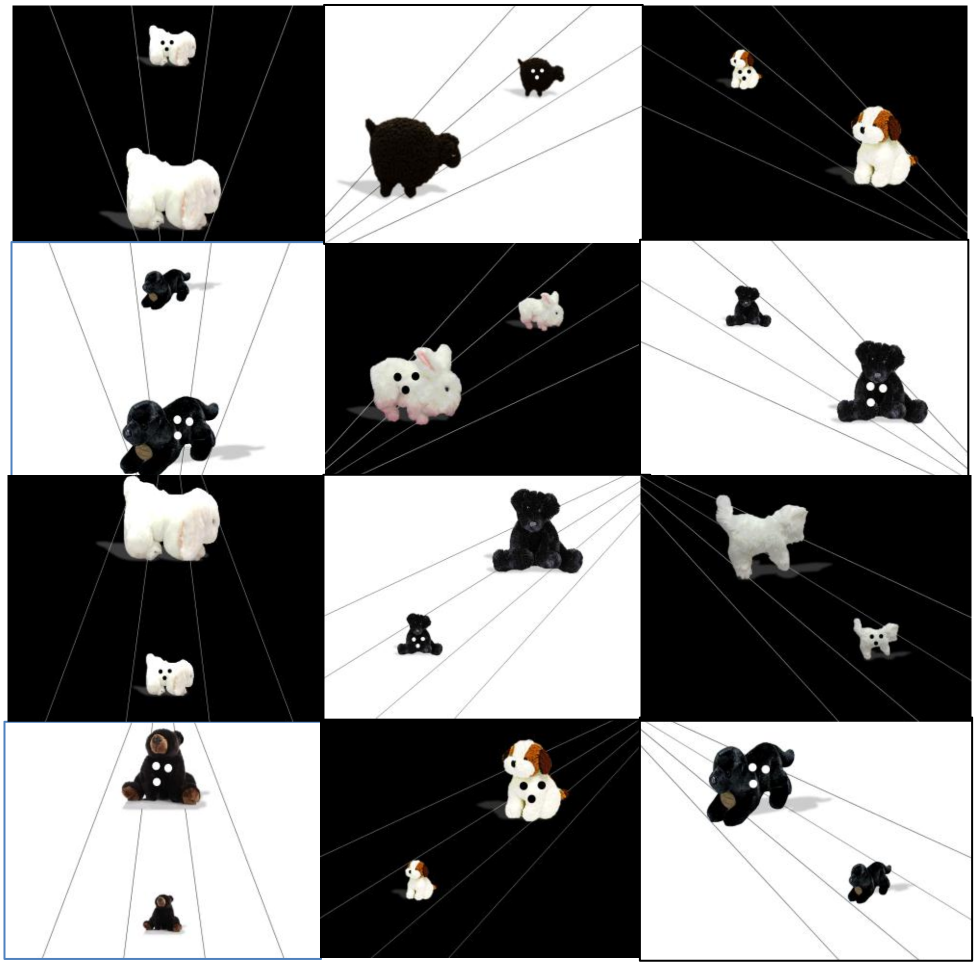

Figure A 3: Four rows of different-size, reversed depth-cue conditions arranged in the order of: Re-0-DS, Re-0-DL, Re-180-DS, Re-180-DL by three columns arranged by the directions of depth cues: vertical, diagonal to the right, diagonal to the left.

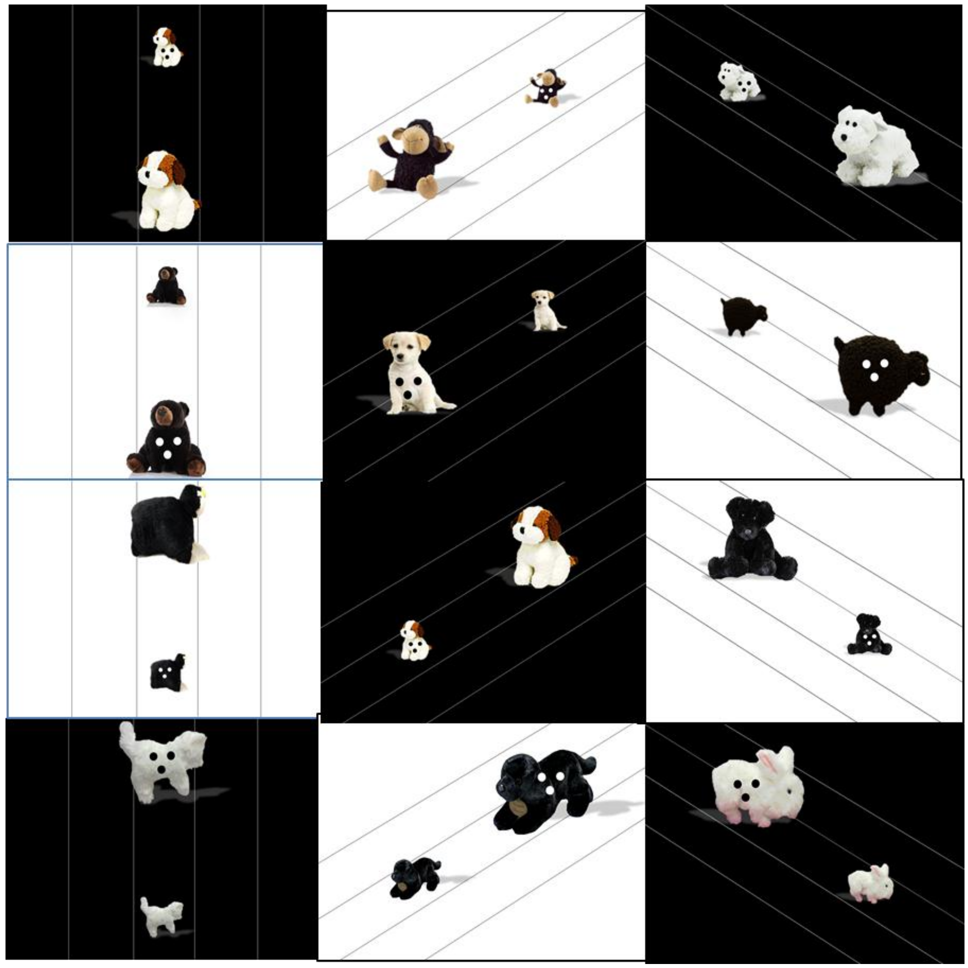

Figure A 4: Four rows of different-size, no depth-cue conditions arranged in the order of: No-0-DS, No-0-DL, No-180-DS, No-180-DL by three columns arranged by the directions of depth cues: vertical, diagonal to the right, diagonal to the left.

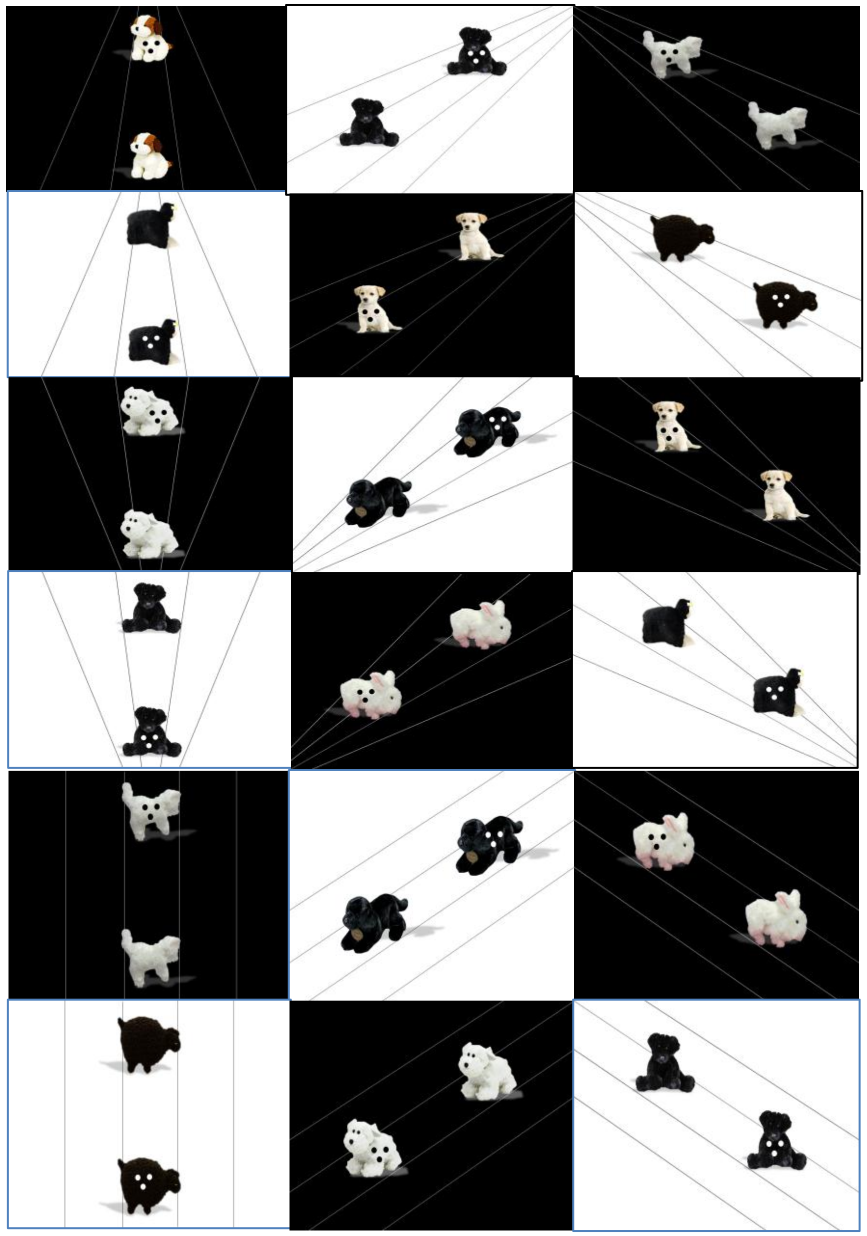

Figure A 5: Two top rows of same-size, congruent depth-cue conditions arranged in the order of: Same-0-DT and Same-0-DB.

Two middle rows of same-size, reversed depth-cue conditions arranged in the order of: Same-180-DT and Same-180-DB.

Two bottom rows of same-size, no depth-cue conditions arranged in the order of: Same-No-DT and Same-No-DB.

The three columns are arranged by the directions of depth cues: vertical, diagonal to the right, diagonal to the left.

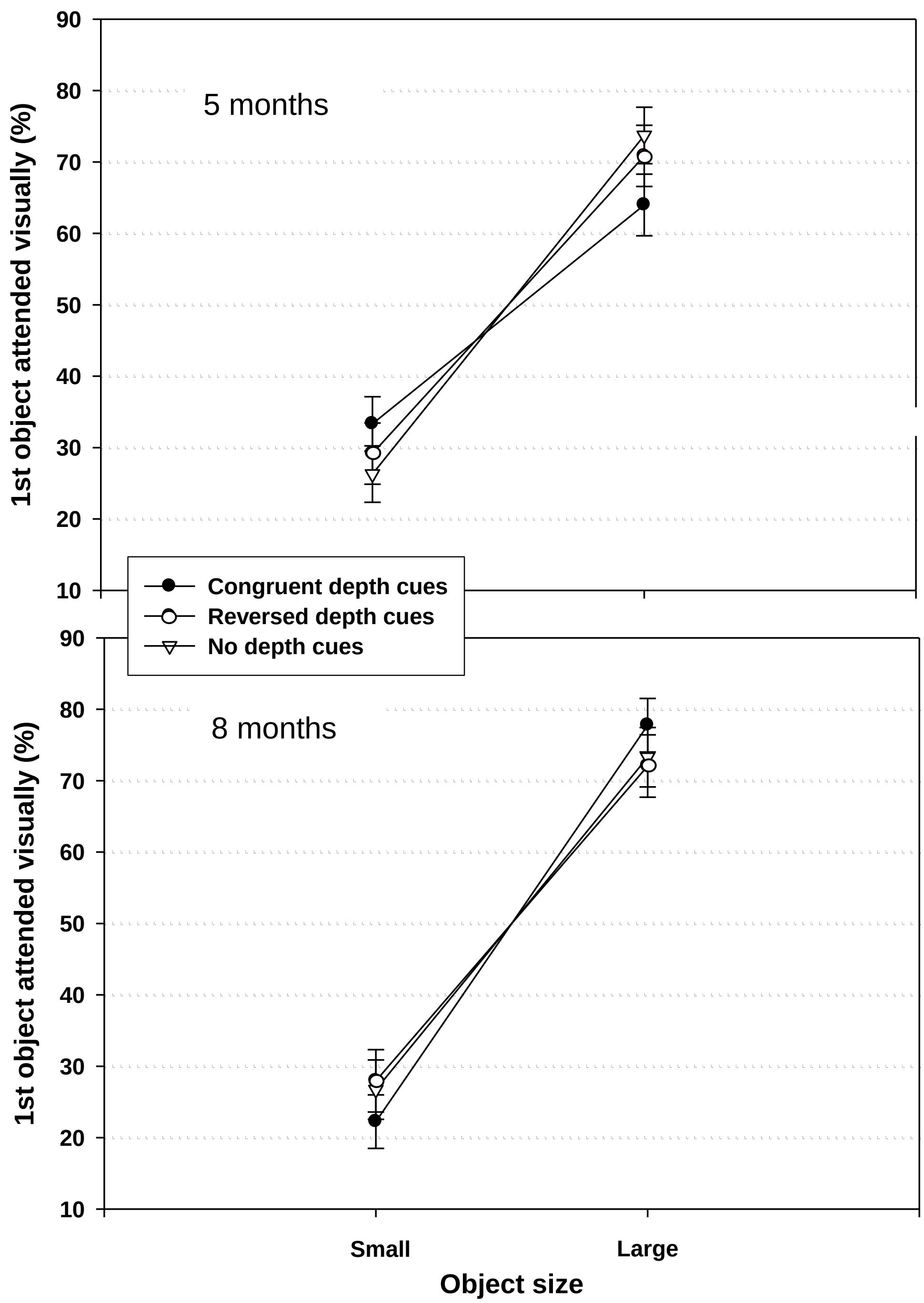

Figure A 6: Experiment 1: mean percentage (and error bars) of object first visually attended in 5 month old age group (top) and 8 month old age group (bottom) in the different-size conditions. The figures were plotted as a function of object size (small, large) and depth cue conditions (congruent, reversed, no depth cues).

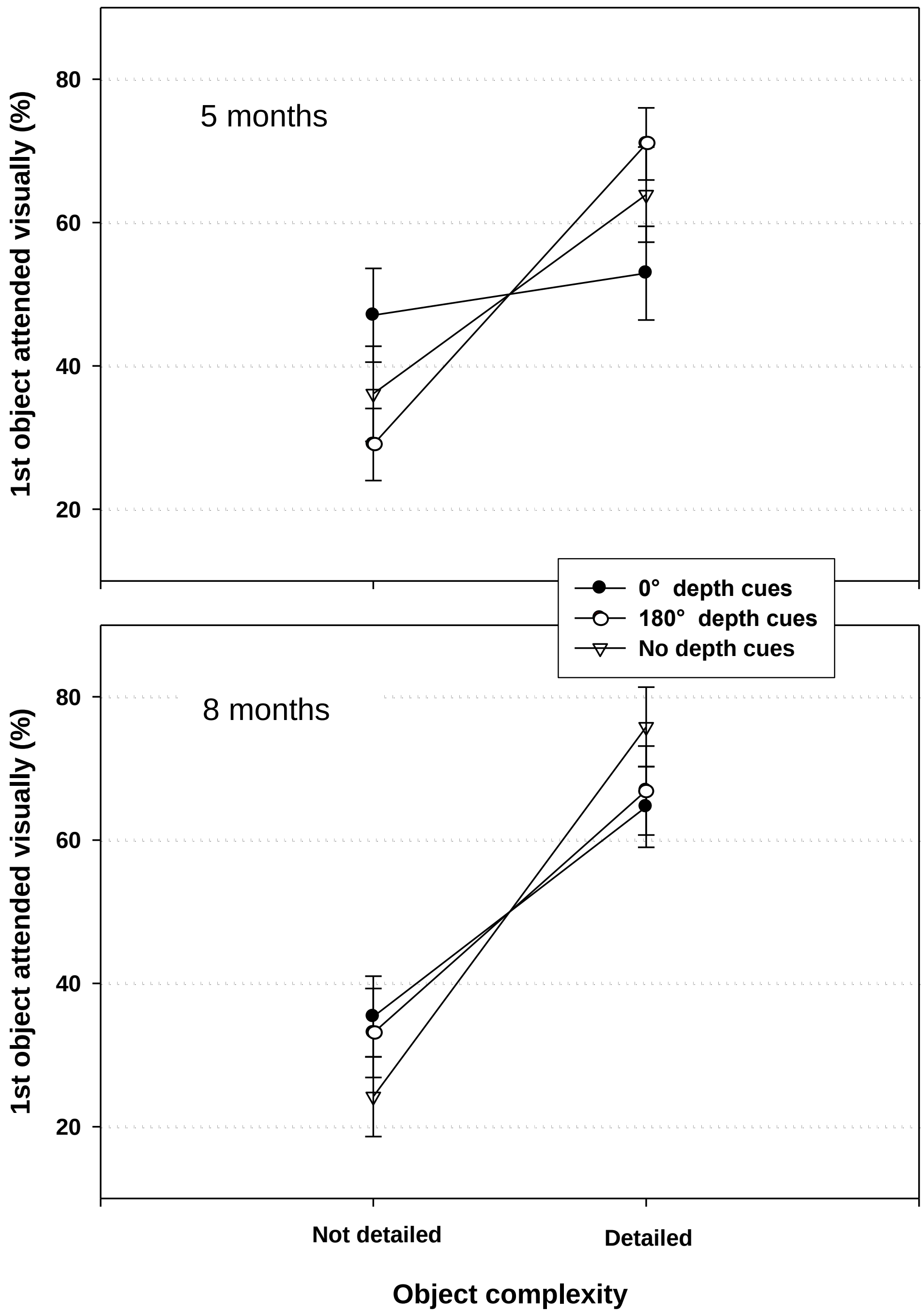

Figure A 7: Experiment 1: mean percentage (and error bars) of object first visually attended in 5 month old age group (top) and 8 month old age group (bottom) in the same-size conditions. The figures were plotted as a function of object detail (detailed, not detailed) and depth cue conditions (0°, 180°, no depth cues).

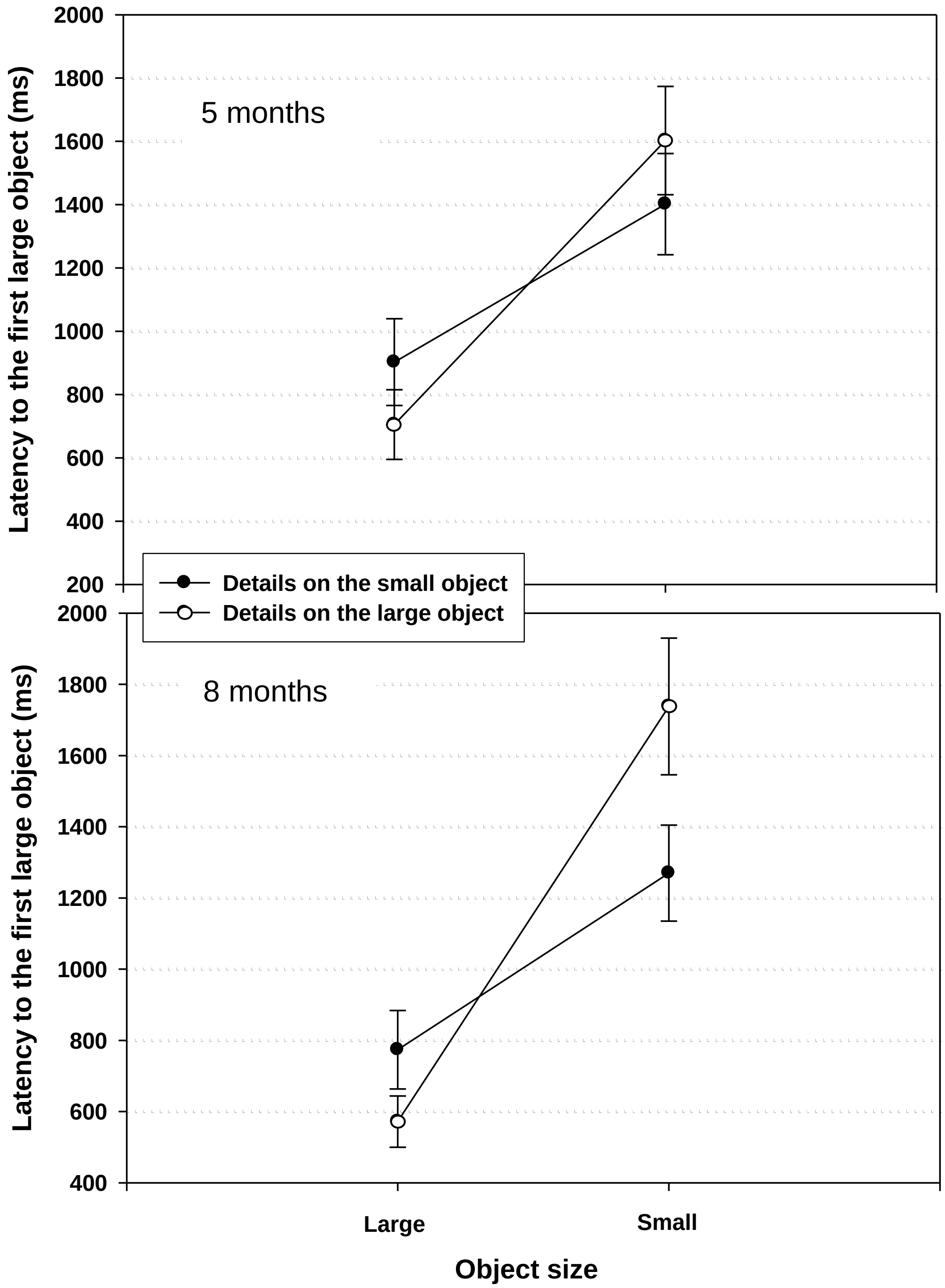

Figure A 8: Experiment 1: mean latency in milliseconds (and error bars) to the first object visually attended for the 5 months old (top) and 8 months old (bottom) groups in all different-size conditions. The figures were plotted as a function of object size (large, small) and detail conditions (detail on the small object, detail on the large object).

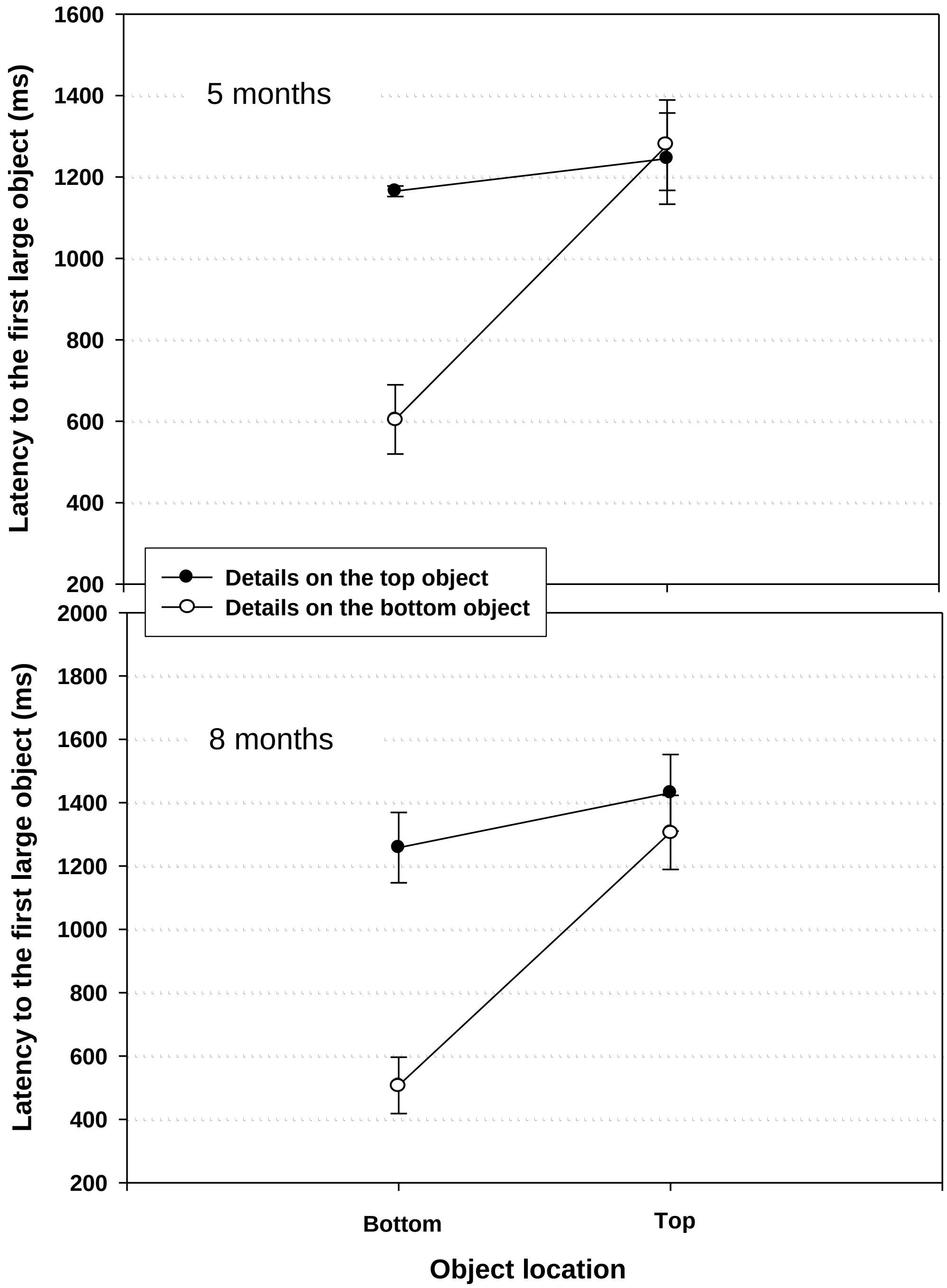

Figure A 9: Experiment 1: mean latency in milliseconds (and error bars) to the first object visually attended for the 5 months old (top) and 8 months old (bottom) groups in all same-size conditions. The figures were plotted as a function of object location (top, bottom) and detail conditions (detail on the top object, detail on the bottom object).

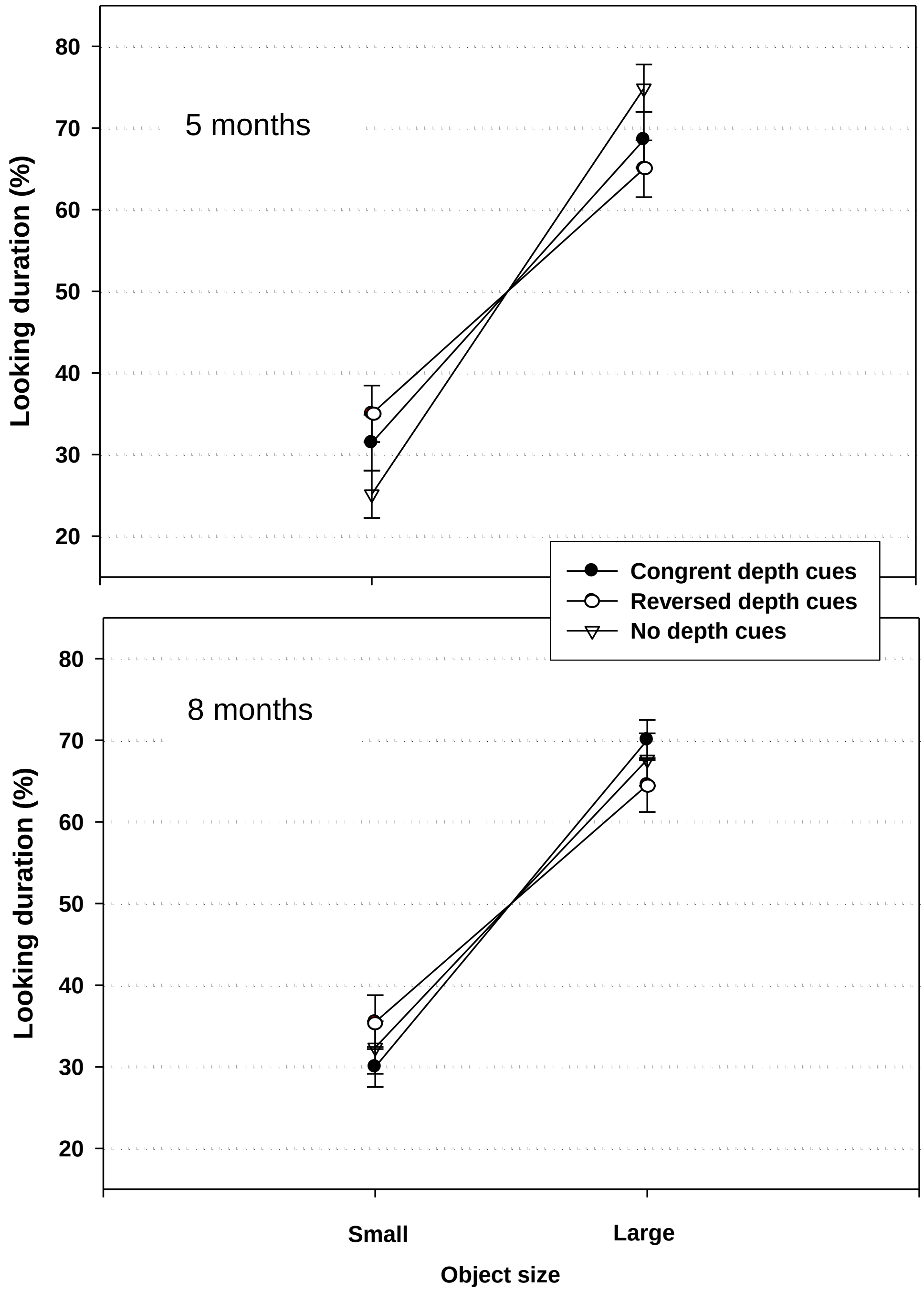

Figure A 10: Experiment 1: mean percentage (and error bars) of looking duration on each object in 5 month old group (top) and 8 months old group (bottom) in the different-size conditions. The figures are plotted as a function of object size (small, large) and depth cue conditions (congruent, reversed, no depth cues).

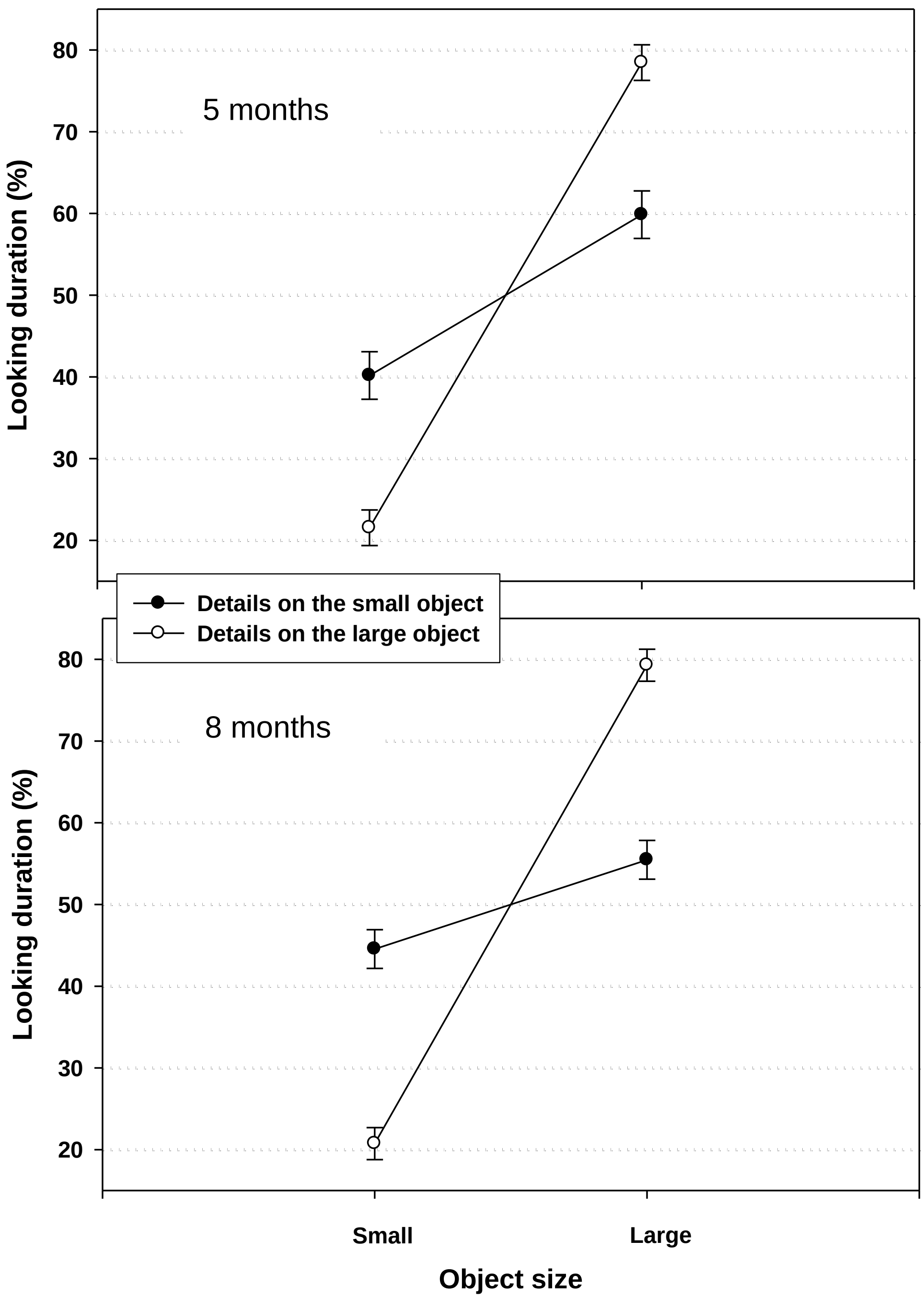

Figure A 11: Experiment 1: mean percentage (and error bars) of looking durations on each object in 5 month old group (top) and 8 month old group (bottom) in the different-size conditions. The figures are plotted as a function of object size (small, large) and object detail conditions (detail on the top object and detail on the bottom object).

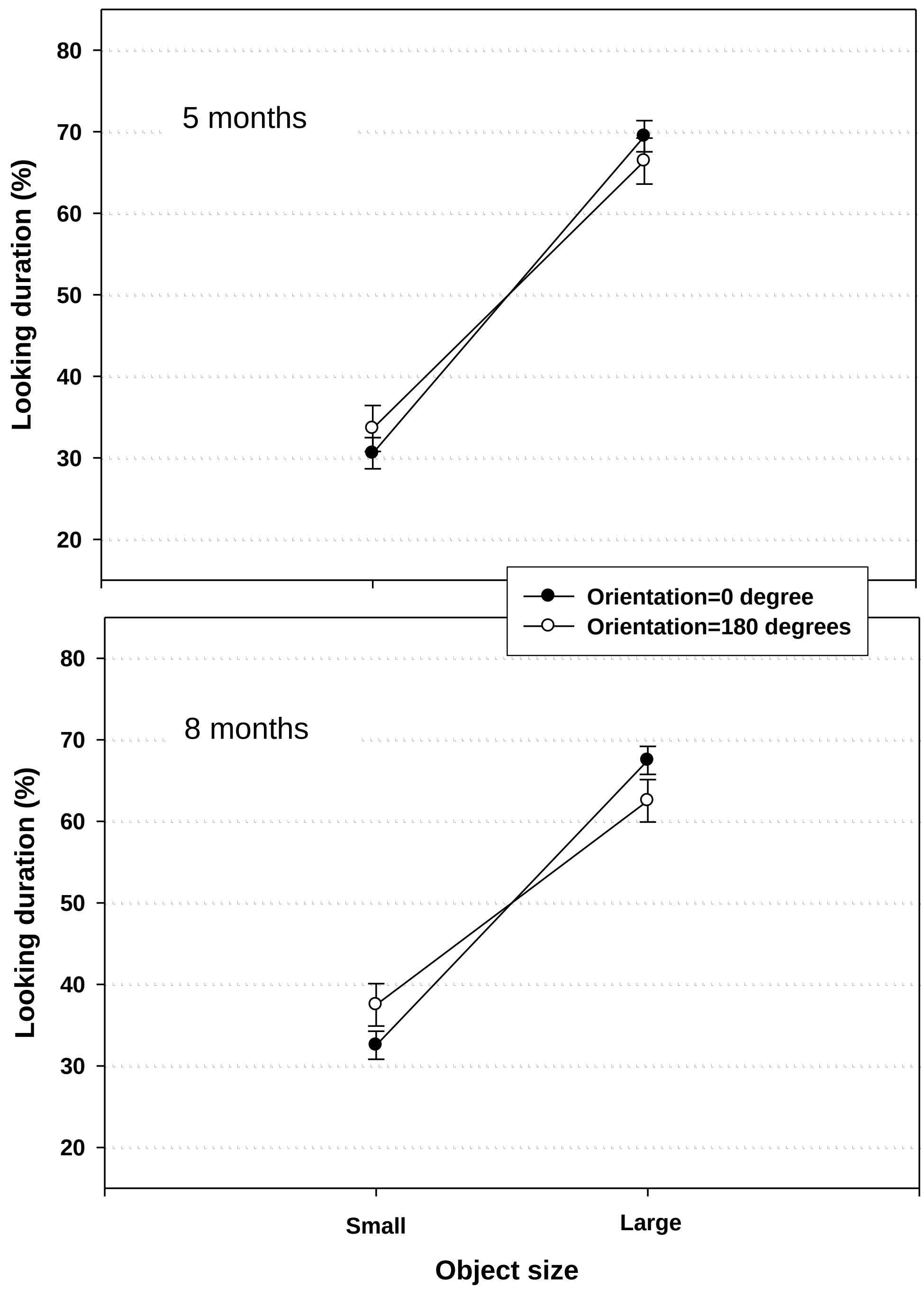

Figure A 12: Experiment 1: mean percentage (and error bars) of looking duration on each object in 5 month old group (top) and 8 months old group (bottom) in the different-size size conditions. The figures are plotted as a function of object size (small, large) and orientation conditions (0° and 180°).

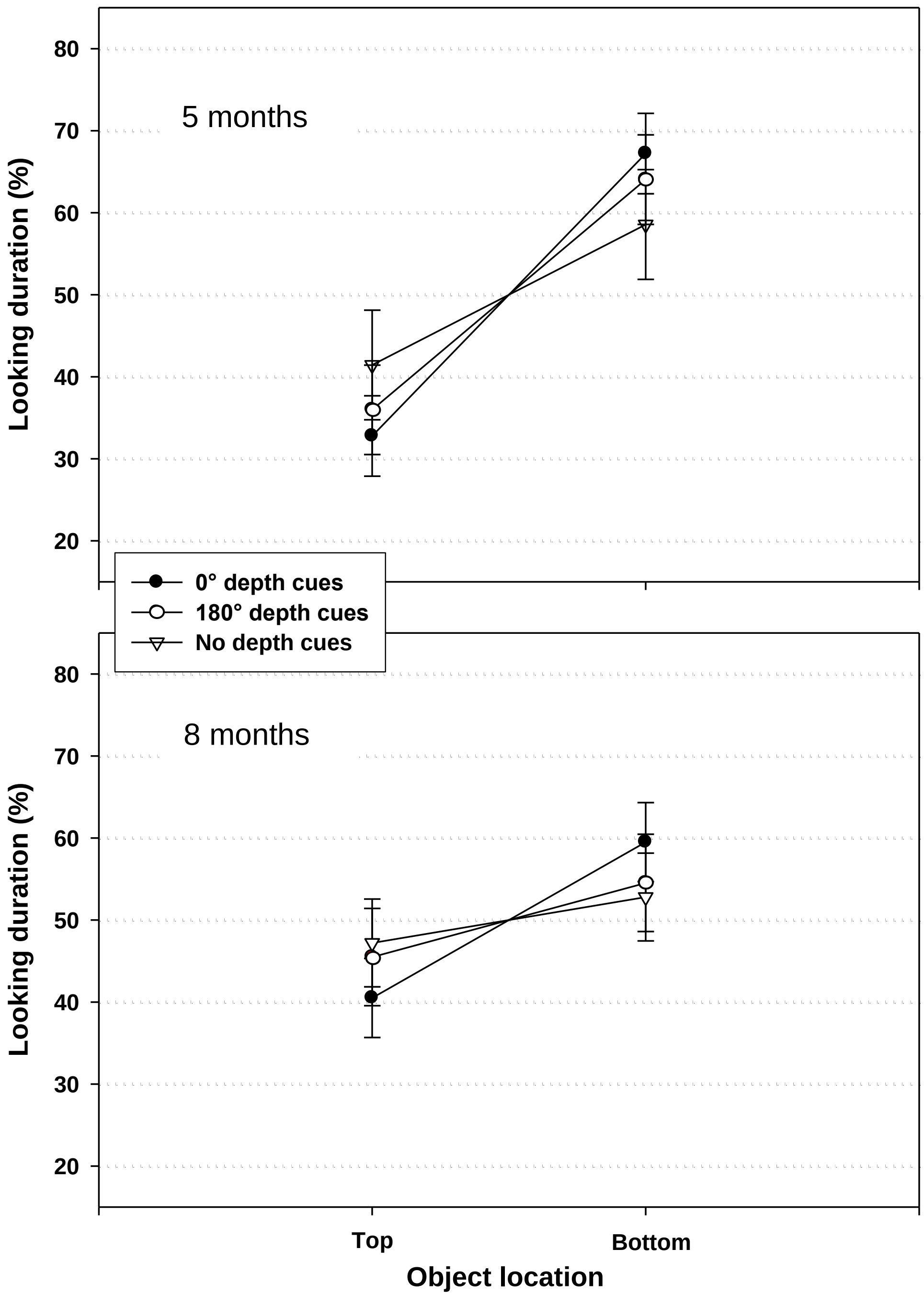

Figure A 13: Experiment 1: mean percentage (and error bars) of looking durations on each object in 5 months old group (top) and 8 months old group (bottom) in the same-size conditions. The figures are plotted as a function of object location (top, bottom) and depth cue conditions (0°, 180°, and no depth cues).

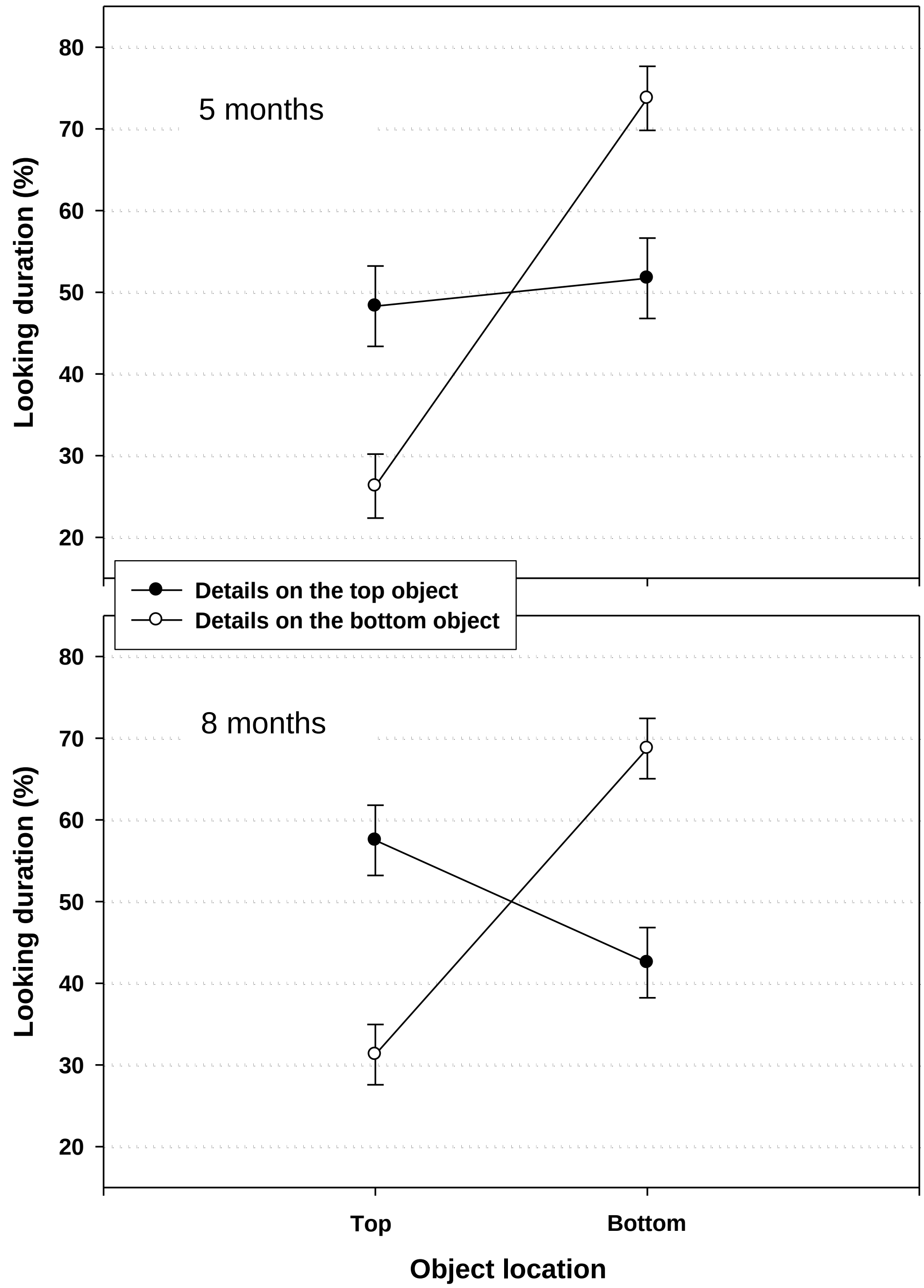

Figure A 14: Experiment 1: mean percentage (and error bars) of looking durations on each object in 5 month old group (top) and 8 month old group (bottom) in the same-size conditions. The figures are plotted as a function of object location (top, bottom) and object detail conditions (detail on the top object and detail on the bottom object).

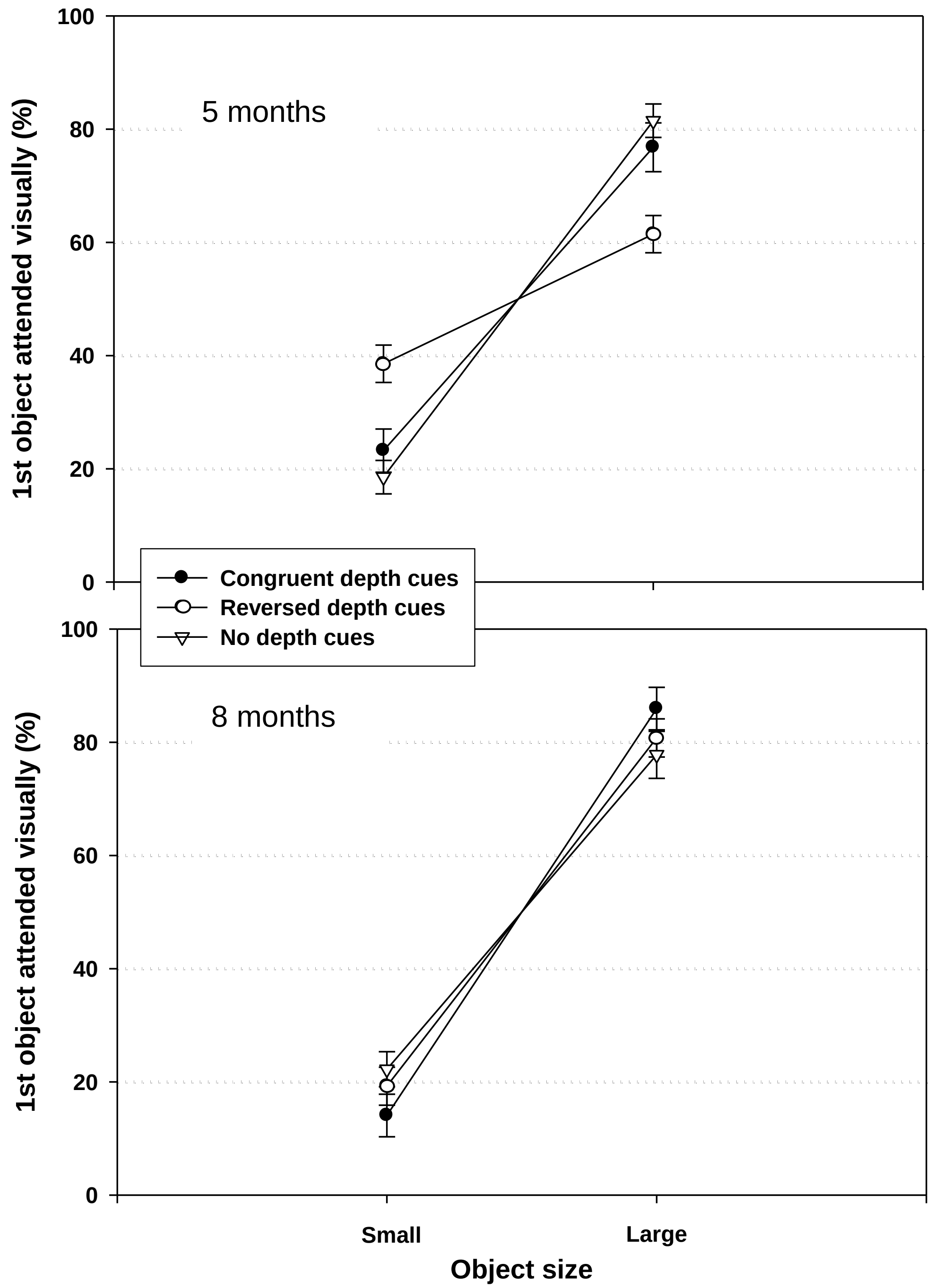

Figure A 15: Experiment 2: mean percentage (and error bars) of object first visually attended in 5 month old age group (top) and 8 month old age group (bottom) in the different-size conditions. The figures were plotted as a function of object size (small, large) and depth cue conditions (congruent, reversed, no depth cues).

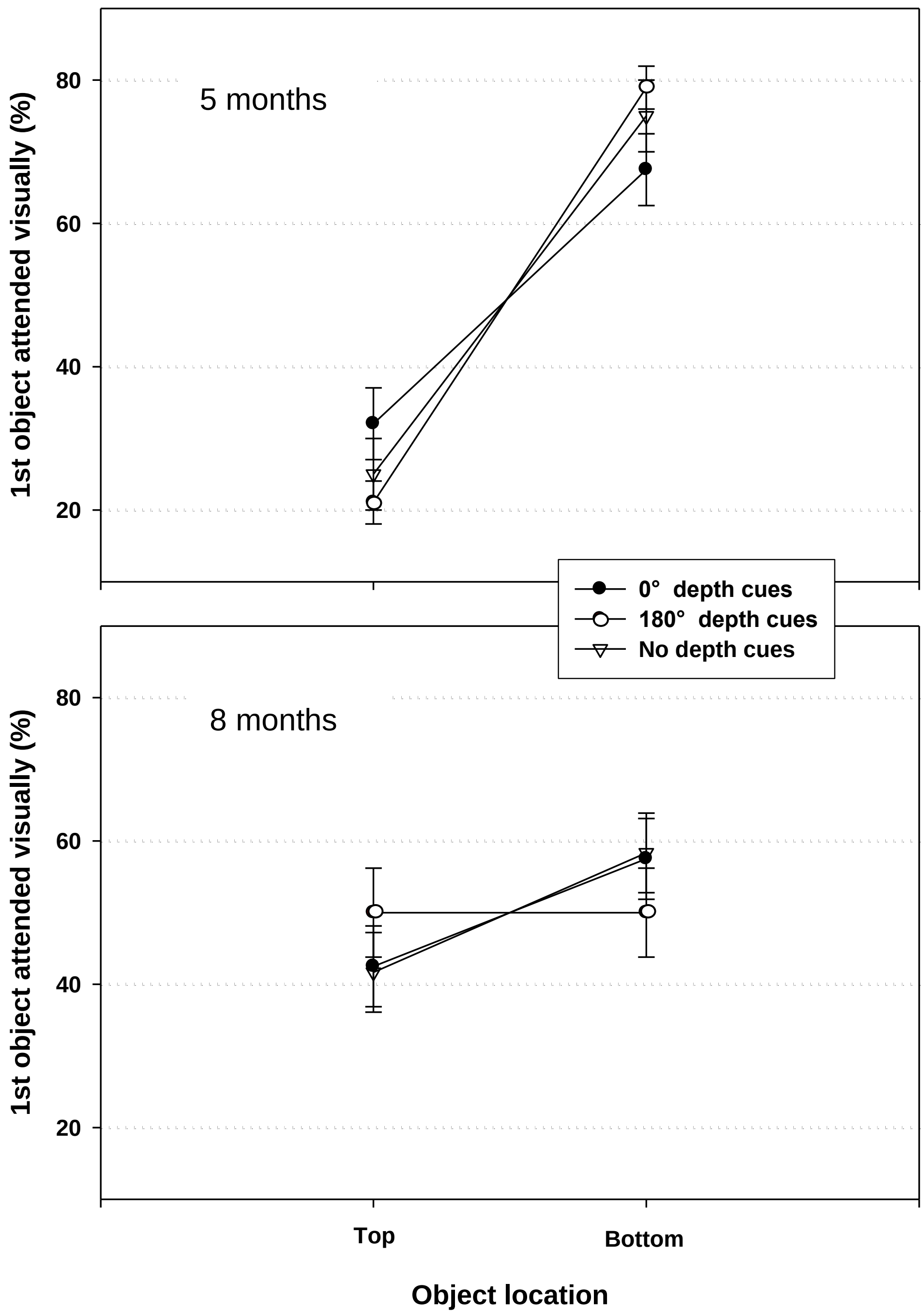

Figure A 16: Experiment 2: mean percentage (and error bars) of object first visually attended in 5 month old age group (top) and 8 month old age group (bottom) in the same-size conditions. The figures were plotted as a function of object locations (top, bottom) and depth cue conditions (0°, 180°, no depth cues).

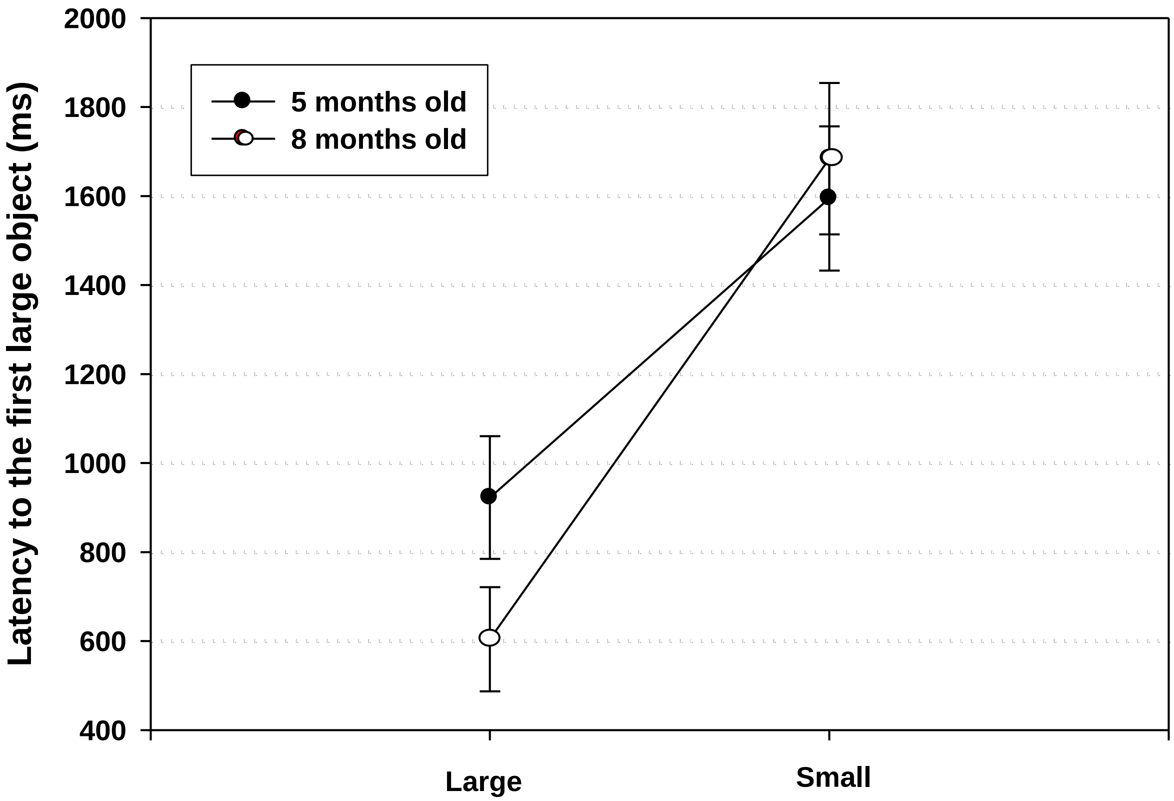

Figure A 17: Experiment 2: mean latency in milliseconds (and error bars) to the first object visually attended in all different-size conditions. The figures were plotted as a function of object size (large, small) and age (5 months old and 8 months old).

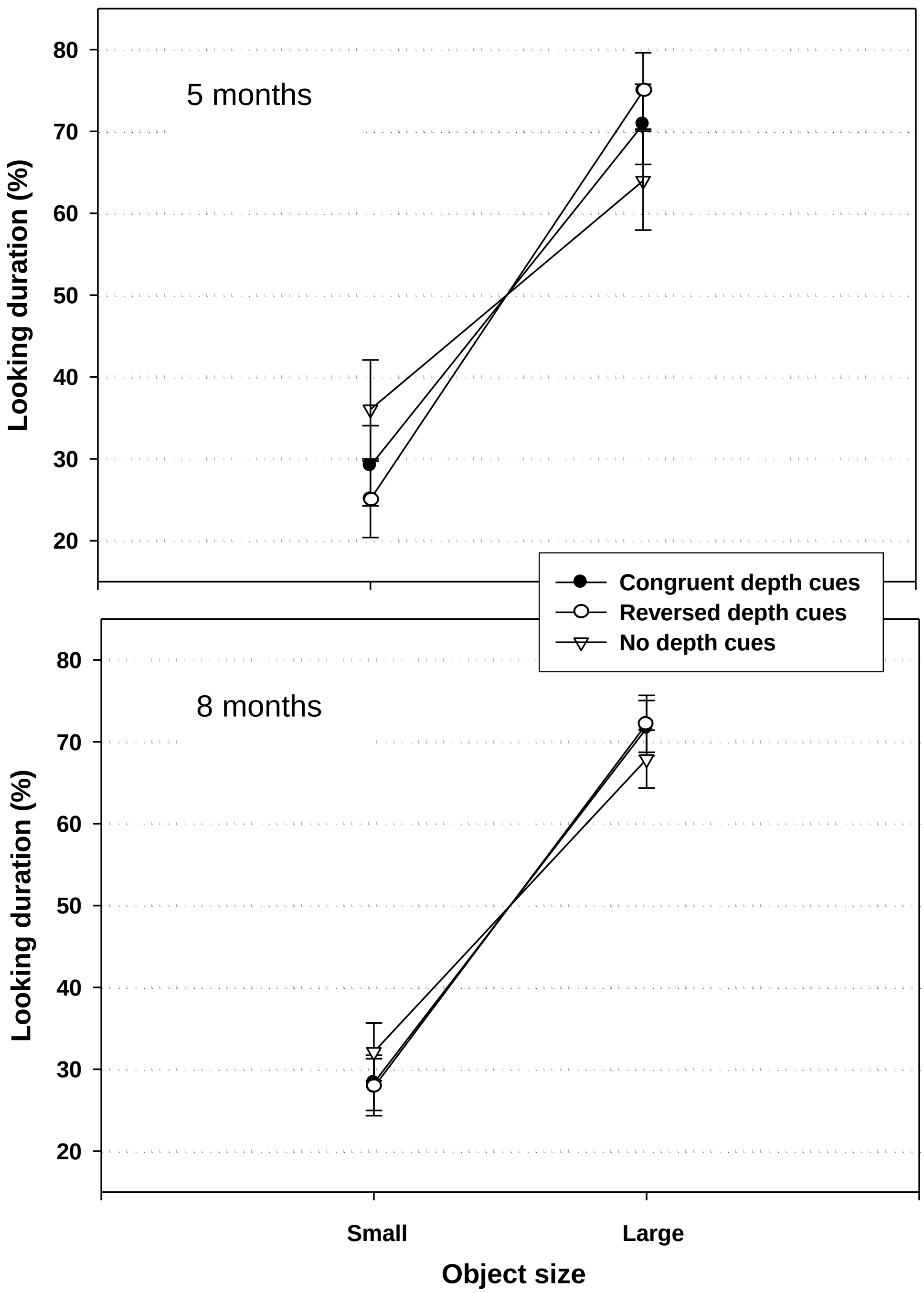

Figure A 18: Experiment 2: mean percentage (and error bars) of looking duration on each object in 5 months old group (top) and 8 months old group (bottom) in the different-size conditions. The figures are plotted as a function of object size (small, large) and depth cue conditions (congruent, reversed, no depth cues).

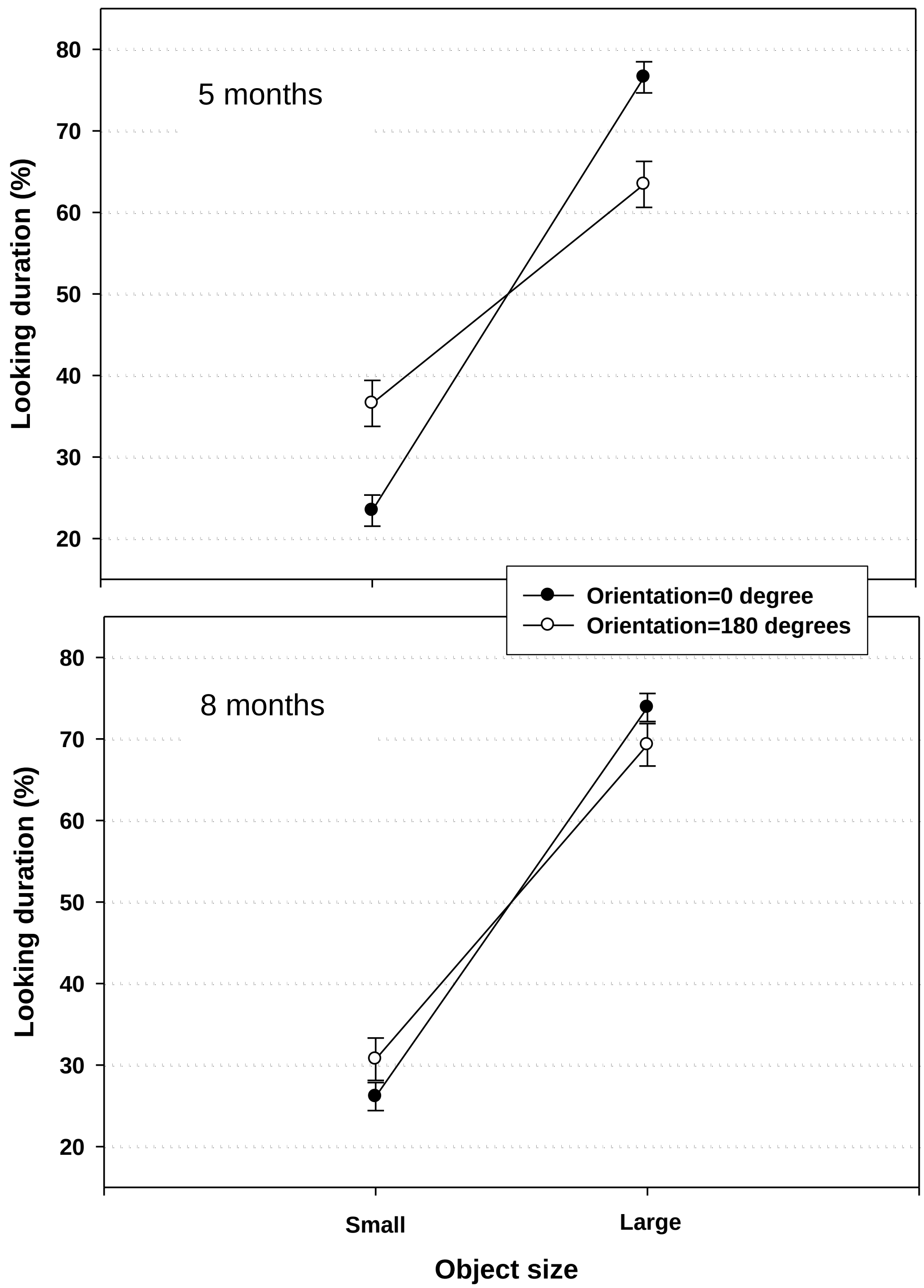

Figure A 19: Experiment 2: mean percentage (and error bars) of looking duration on each object in 5 month old group (top) and 8 months old group (bottom) in the different-size size conditions. The figures are plotted as a function of object size (small, large) and orientation conditions (0° and 180°).

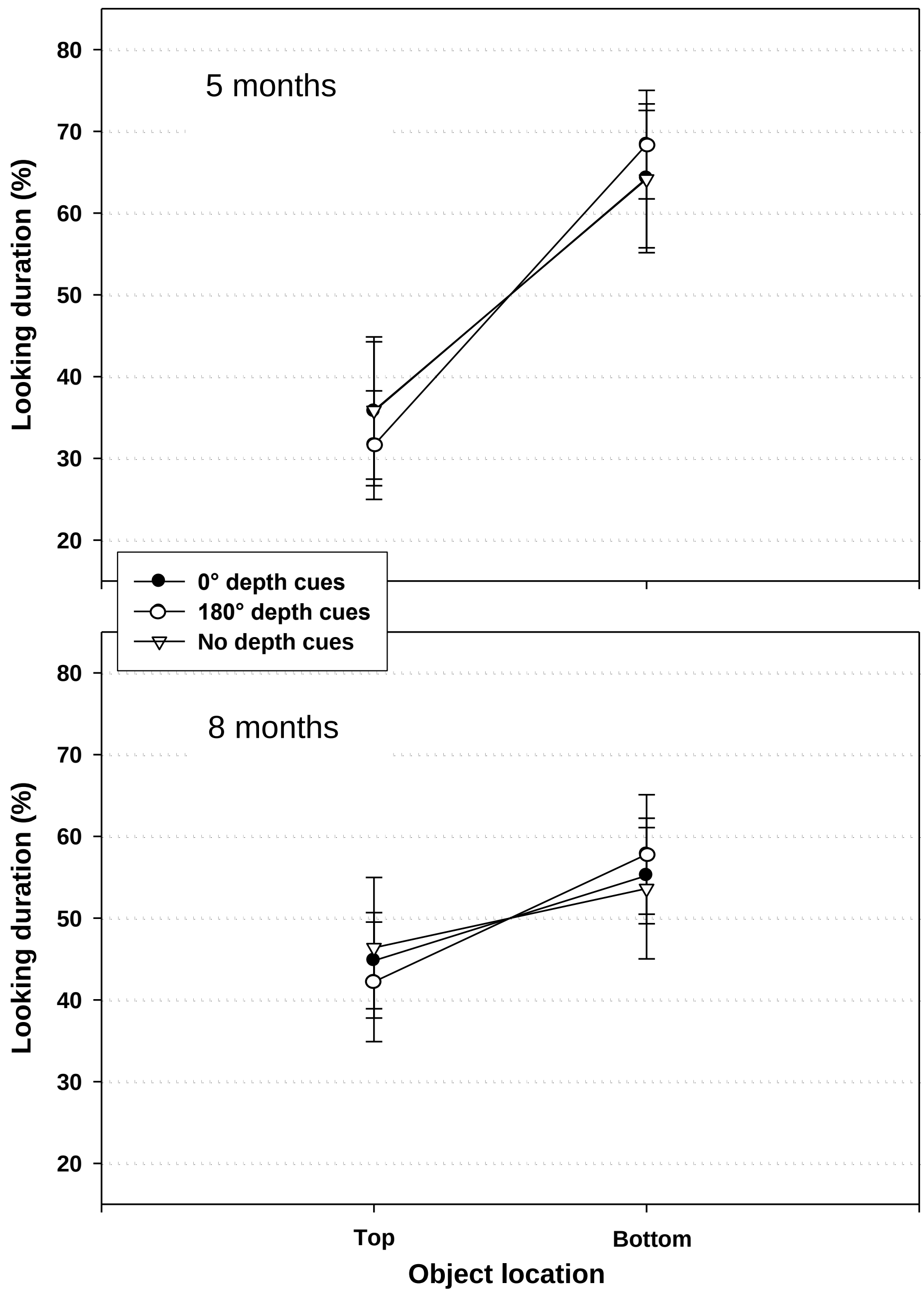

Figure A 20: Experiment 2: mean percentage (and error bars) of looking durations on each object in 5 months old group (top) and 8 months old group (bottom) in the same-size conditions. The figures are plotted as a function of object location (top, bottom) and depth cue conditions (0°, 180°, and no depth cues).

Vita

Yu Guan was born in Qingdao, China on October 16, 1984. She received her B.S. in clinical psychology from Shandong University of Tradition Chinese Medicine in May 2007.