PERCEPTION OF THREE-DIMENSIONAL SHAPE FROM STUCTURE-FROM-MOTION (SFM) STIMULI IN INFANCY

A Thesis

by

AMY HIRSHKOWITZ

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2012

Major Subject: Psychology

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Approved by:

Chair of Committee,	Teresa Wilcox
Committee Members,	Gerianne Alexander
	Carl Gabbard
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ABSTRACT

Perception of Three-Dimensional Shape from Structure-from-Motion (SFM) Stimuli in Infancy. (May 2012)

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Three-dimensional (3D) object perception is critical for comprehending and interacting with the world. It develops during infancy and continues through adulthood. One powerful cue used for object perception is uniform coherent motion. The present paper first briefly reviews the current literature concerning object perception using random-dot stimuli and structure-from-motion (SFM) displays. To extend our knowledge in this area, two new studies were conducted to further our understanding of how infants process 3D shape in SFM stimuli.

Study 1 examined infants of two age groups (3-5 month-olds and 8-9 month-olds) in a familiarization phase and a test phase. In the familiarization phase, infants were exposed to one of two SFM shapes (cube or cylinder) and in the test phase infants viewed both SFM shapes side-by-side. Extraction of shape was measured through novelty preferences. Results of Study 1 suggest that both age groups successfully extracted 3D shape. Study 2 served as a replication and extension, with the added control for the variable rotational axis. When this variable was controlled for, 3-5 month-olds failed to show a novelty preference during the test phase. These results suggest not only that infants were attending to both the global shape presented in the SFM stimuli as well as the detailed component of the rotational axis of the stimuli, but also that adding the extra change in the component of rotational axis to SFM stimuli makes the task of extracting shape more difficult for infants. These findings contribute to the infant literature by furthering the understanding of infant shape perception.

DEDICATION

To my family

ACKNOWLEDGEMENTS

I would like to thank my advisor and committee chair, Dr. Wilcox, as well as my committee members, Dr. Alexander and Dr. Gabbard for their guidance, patience, and support throughout the course of this research.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Object perception is fundamental for both comprehension of and interaction with the world. Understanding not only that objects are solid-bounded entities, but also that objects maintain a stable shape regardless of the human viewpoint is essential for object perception. These basic understandings typically develop between 2 and 5 months of age (Needham, 1999; Wilcox, 1999), with even young infants showing the ability to use stationary perceptual depth cues such as shading and line junctions to extract object shape (Bhatt & Waters, 1998; Tsuruhara, Sawada, Kanazawa, Yamaguchi, & Yonas, 2009; Tsuruhara, Sawada, Kanazawa, Yagamuchi, Corrow, & Yonas 2010). One powerful cue for object perception used by both adults and infants is coherent motion. Objects are composed of elements linked together. These elements can be surfaces (in two dimensions) or wholes (three dimensions) and lie on the same dimensional plane. When the elements have a uniform direction and velocity of motion, the movement is coherent and gives rise to the percept of shape.

For example, occlusion of objects is a cue that adults use regularly in depth perceptions- adults know that objects which are occluded behind other objects are further away than the occluding objects. At an even more basic level, adults perceive that the objects behind the occluders as whole objects. Adults will segregate an object from an occluder the object sits behind by using featural cues such as color and shape;

This thesis follows the style of *Developmental Science.*

when young infants are presented with a rod behind an occluder, however, they will only view the rod behind an occluder as continuous unit separate from the occluder when the two visible surfaces of the rod move together and the occluder remains stationary (Kellman & Spelke, 1983). In this case, the pieces of the rod form a surface that moves coherently and thus, give rise to the percept of a complete rod that moves behind the occluding block. Surfaces and whole objects can also be composed of random-dot elements that move together on the same planes to give rise to two-dimensional (2D) and three-dimensional (3D) shapes. Coherent motion is a necessity for young infants' understanding of object unity, completion, and identity (Kellman & Spelke, 1983; Johnson, 2004; Soska & Johnson, 2008; Johnson, 2010). Coherent motion is particularly salient to infants and facilitates the segregation of objects and the extraction of the shape of objects in both 2D and 3D perception.

1.1 Using Motion to Discriminate Two Dimensions (2D)

One method for studying 2D percepts employs basic achromatic random-dot stimuli. These simple stimuli in which dots move together coherently can provide definition of boundary percepts. Understanding where one object in space ends and another begins allows both infants and adults to segregate and integrate their worlds (Spitz, Stiles, & Siegal, 1993).

Both infants and adults use coherent motion in their perceptions of boundaries and surfaces. When given the choice of looking at random-dot stimuli displays containing no visible contours and displays containing visible contours (defined by three coherent motion directions in which the top and bottom of the display moved in one direction and the center of the display moved in the opposite direction), 2-month-olds will look reliably longer at the displays with visible contours and multiple directions of motion than those without visible contour (Johnson, Davidow, Hall-Haro, & Frank, 2008). Infants at this age will also reliably dishabituate to a novel 2D shape on a screen composed of random-dot elements when motion serves as the only definitive cue for contour perception (Johnson & Mason, 2002). By 7 months of age, infants will discriminate between coherent motion (dots moving together in a specified direction) and incoherent motion (dots moving randomly) as well as between different types of coherent motion (Spitz *et al.*, 1993).

The adult literature of 2D percepts in random-dot stimuli is consistent with the infant literature: coherent motion is fundamental for contour and surface perception. Like infants, when adults are provided with a stationary view of a basic random-dot stimulus, they are unable to specify the percept of shape (Johnson & Mason, 2002). Coherent motion is the key aspect that allows for shape perception, and factors that affect shape perception with coherent motion stimuli in infants can also affect adult percepts. For example, one factor that affects 2D shape perception is the grouping of the random dots. To make the boundary percept stronger, the density (number of random dot elements) can be increased (Anderson & Cortese, 1989; Bex, Simmers, & Dakin, 2003). A second factor that affects 2D shape perception is the velocity of the random dot elements: to make the boundary percept stronger, the speed of the random dots can be increased (Anderson & Cortese, 1989; Bex *et al.*, 2003). These factors suggest that perceptions change based on the parameters of visual input.

Although it is clear that random-dot stimuli can be used to explore the segregation of objects and extraction of the shape of objects in 2D percepts, most of our world is 3D. Further studies using random-dot stimuli also explore 3D shape percepts.

1.2 Using Motion to Discriminate Three Dimensions (3D)

Three-dimensional object perception is more complex than 2D shape perception because there is an added axis of space with just as many or more boundaries and surfaces for humans to process at any given time. Additionally, 3D objects are rarely symmetrical in their entirety. Coherent motion facilitates 3D shape perception.

One study that highlights the necessity of coherent motion for object perception was performed by Kellman and Short (1987). These authors used a more traditional infant methodological approach to test infants' ability to identify 3D form with the use of wire parallelogram figure stimuli. Four month-old infants were tested in one of two conditions: a) a static condition or b) a kinetic condition. In the static condition the wire figures were occluded while they underwent rotation so that infants viewed the figures as images in all of the different rotations without viewing the motion of the rotation itself. In the kinetic condition the wire figures were shown rotating continuously. All stimuli were viewed on a video monitor. In habituation trials infants viewed one of two objects. Half of the infants viewed a wire parallelogram figure in which the two triangles making up the parallelogram figure intersected at 95° and the other half of the infants viewed a wire parallelogram figure in which the two triangles making up the parallelogram figure intersected at 165°. In all habituation trials infants viewed the wire objects rotating about a vertical axis; the objects, however, were attached to the axis in two different places for alternate habituation trials. Habituation trials were repeated until the habituation criterion was met, at which point the infant then viewed test trials. In the test trials infants viewed both wire parallelogram figures in alternation: one familiar wire figure (the same intersection angle of the two triangles) and one novel wire figure (the other intersection angle of the two triangle figures not previously viewed in habituation trials). In all test trials both familiar and novel parallelogram figures rotated on a third novel vertical axis not seen during habituation.

Results of this experiment found that infants in the kinetic condition who viewed the wire parallelogram figure that had the triangles point of intersection at 165° reliably dishabituated to the novel wire parallelogram figure that had the 95° angle of intersection at test, while infants in the static condition did not reliably dishabituate. This suggests that infants extracted the 3D structure of the object seen during the habituation trials and recognized the object from a new perspective. Additionally, the infants perceived the new shape as novel and looked significantly longer at it. The coherent motion provided in the stimuli was a necessity for the infants, and also contributes to the salience of adult perception. Adults given the same stimuli did not perform above chance levels in the absence of coherent motion.

The study just described used video recordings of physical stimuli to explore 3D percepts. Random-dot stimuli can also be used for this purpose. The use of the combination of random-dot stimuli and coherent motion within those stimuli for the extraction of 3D shape by humans is often referred to as structure-from-motion (SFM). As with coherent motion in random-dot stimuli giving rise to 2D percepts, the 3D percepts of SFM can be affected by factors such as density and velocity (Lappin, Doner & Kottas, 1980; Braunstein, Hoffman, & Pollick, 1990; Anderson & Bradley, 1998). SFM research is well established throughout the adult literature (Gilroy & Blake, 2004; Murray, Schrater, & Kersten, 2004; Tittle, Todd, Perotti, & Norman, 1995), however SFM stimuli in the infant literature is more limited.

A study performed by Arterberry and Yonas (1988) suggests sensitivity to SFM stimuli in very young infants. Four month-old infants were habituated to 3D-appearing SFM stimuli in the form of a cube. Infants in the full-view condition saw a full cube with a convex space cut out in the far corner (i.e. unnoticeable). Infants in the partial-view condition, in contrast, saw a cube with the front corner cut out, or a concave corner. At test infants viewed the two shapes in alternation. Results indicated that infants in both conditions showed a novel structure preference: infants in the full-view condition looked longer at the partial cube and infants in the partial-view condition looked longer at the full cube. A more recent study (Arterberry & Yonas, 2000) demonstrated that 2-month-old infants did not show a preference, however: the infants in the full-view condition showed a novel preference at test while the infants in the partial-view condition showed no preference. These ambiguous results with the 2-month-olds suggest that the 3D perception of part of a cube is important.

1.3 Present Research

Despite the fact that the process of extracting 3D shape is critical for human perception, and there is an enormous amount of SFM research in adults (Gilroy & Blake, 2004; Murray *et al.*, 2004; Tittle *et al.*, 1995), little is known about development during infancy. Infants clearly use motion as a cue in their perceptions of boundaries, surfaces, and structure, but the extraction of 3D shape from coherent motion still remains a question (Johnson *et al.*, 2008; Johnson & Mason, 2002; Arterberry & Yonas, 1988; Arterberry & Yonas, 2000). The present paper conducted two studies with the aim of using SFM stimuli to further explore 3D object perception in young infants. Infants were shown random-dot stimuli in which dots moved in a coherent or non-coherent (random) way. Dots in these stimuli moving in a coherent way gives rise to the percept of shape in adults (Murray, Kersten, Olshausen, Schrater, & Woods, 2002). If infants also use coherent motion in these random dot displays they will detect the shape. The research question examined in the first study, then, was whether infants will extract 3D shape in SFM displays. Successful shape extraction was measured by novelty preferences during test trials.

2. STUDY 1

2.1 Method

Participants

Study 1 recruited 35 infants in the age ranges of 3-5 months (14 infants; 7 males and 7 females, mean age 4 months and 22 days) and 8-9 months (21 infants; 10 males and 11 females, mean age 9 months and 6 days). Names of parents with infants were found through commercially produced lists. Letters about the study were mailed, and phone calls were be made to schedule in Texas A&M's Infant Cognition Lab. Brochures were also sent out to the local Bryan-College Station hospitals to be included in informational packets given to new parents.

Materials and Design

All stimuli in Study 1 were borrowed from Murray et al. (2002). These included three types of stimuli: a) SFM stimulus composed of white random dots moving against a black background in the form of a geometric shape (either a cube or a cylinder), b) Random motion (RM) stimulus composed of white random dots moving against a black background without any coherent shape, and c) Flashing static white random-dot stimulus against a black background (See Figure 1).

All three types of stimuli were composed of 450 white dots and took up approximately 14% of the screen (screen size 51 x 32cm). The SFM stimulus had the white dots orthographically projected onto one of the geometric shape (cube, cylinder) planes. The shape planes rotated 30° about a 3D axis (either x-axis or y-axis), and the white dots were fixed to move upon the rotational plane of the 3D shape. The RM stimulus had the white dots begin scrambled, with each dot from the SFM stimulus acquiring another dot's velocity to achieve the scrambled pattern. Over the course of the trial the scrambled pattern moved toward the orthographical projection of the shape (cube or cylinder) stimulus. The static stimulus was one fixed random-dot scrambled image (unviewed in SFM and RM stimuli) "flashing" – the flashing effect of the image was achieved by having the dots alternate between white and grey against a black background.

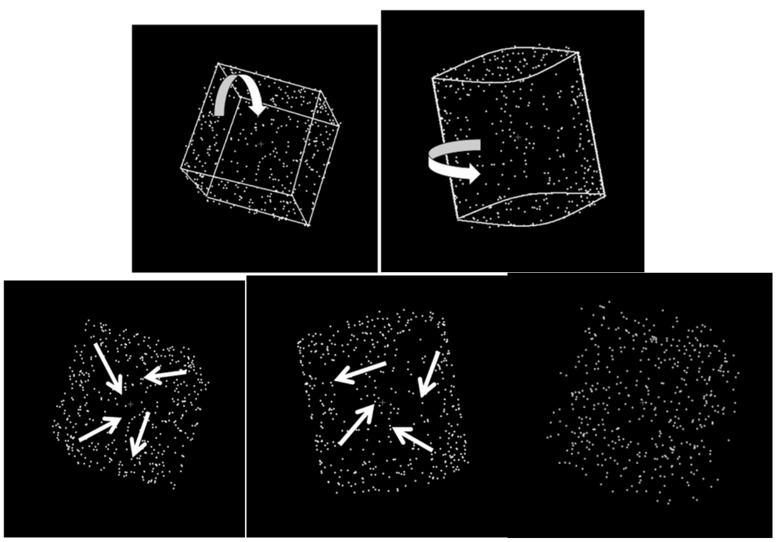

Figure 1 *Stimuli used in Study 1. SFM shapes cube and cylinder (top), random motion shapes cube and cylinder (bottom), and static stimuli (bottom). White outlines and arrows demonstrate 3D percept and motion direction with coherent motion cue; actual stimuli lack contour cues.*

All younger infants (3-5 months) saw 4 familiarization blocks of stimuli, and all older infants (8-9 months) saw 2 familiarization blocks of stimuli. Younger infants received extra familiarization blocks to ensure an adequate amount of exposure to this complex type of stimuli. Each block consisted of one SFM stimulus, one RM stimulus, and 2 static stimuli. Static stimuli were placed between SFM and RM stimuli (e.g. static-SFM-static-RM or static-RM-static-SFM). SFM and RM trials lasted 5 seconds; static trials lasted 10 seconds. SFM and RM trials always alternated, however, the order in which they were presented (SFM first or RM first) was counterbalanced across subjects. SFM stimulus shape was also counterbalanced: half the infants saw the cube stimulus during the block trials; the other half saw the cylinder stimulus during the block trials.

Since infants viewed repeated multiple trials of stimuli (young infants viewed 4 SFM stimuli and 4 RM stimuli; older infants viewed 2 SFM stimuli and 2 RM stimuli), Stimulus was calculated as a mean duration of looking across the SFM stimuli and the RM stimuli, respectively. In the younger infant sample SFM trial contribution, eight infants contributed 4 trials, three infants contributed 3 trials, two infants contributed 2 trials, and one infant contributed 1 trial. In the younger infant sample RM trial contribution, five infants contributed 4 trials, seven infants contributed 3 trials, and two infants contributed 2 trials. In the older infant sample SFM trial contribution, eight infants contributed 4 trials, three infants contributed 3 trials, two infants contributed 2 trials, and one infant contributed 1 trial. In the older infant sample RM trial contribution, five infants contributed 4 trials, seven infants contributed 3 trials, and two infants contributed 2 trials.

After viewing two blocks of shape stimuli, all infants saw 2 test trials with both SFM shapes in rotation. Test trials were 5 seconds each. One test trial contained the SFM stimulus shape (cube or cylinder) the infant saw previously within the initial trial blocks (familiar shape) as well as the other SFM shape stimulus not viewed during the initial block trials (novel shape) rotating side-by-side. Another test trial contained both the familiar and the novel shape side-by-side rotated 180° (mirror image) undergoing rotation. Presentations of test trials were counterbalanced.

To examine whether infants looked differently to the two SFM shape stimuli during test trials (novel shape, familiar shape); test novelty preference scores were calculated. Test novelty preference score calculations were as such: (novel/novel + familiar) for each test trial. Novelty preference scores were calculated for both dependent variables: total fixation duration and total number of fixations to the stimuli, respectively. In the younger infant sample, fourteen infants contributed data to test trial 1 and thirteen infants contributed data to test trial 2. In the older infant sample, twelve infants contributed data to test trial 1 and nineteen infants contributed data to test trial 2.

Procedure

Infants were seated in a parent's lap 65cm away from a Tobii T60 XL monitor, which presented the stimuli. Stimuli presentations were controlled by an experimenter behind a curtain from a Dell Precision M6400 laptop computer with a Windows XP operating system. The Tobii T60 XL monitor was set to 32-bit color and screen size to

1024 x 768 pixels. A Logitech Webcam Pro 9000 was also used to record infant behavior.

The testing room was darkened and dark curtains hung from the ceiling to surround the chair in which parents sat (infant on lap) to help eliminate distractions. Parents were asked to look down at their infant's head so the eye-tracker would not pick up their eyes. This also assured that parents' views of the stimuli did not influence their infants' looking. The experimenter used the Tobii Studio infant calibration setting to gain a calibration of the infants' eyes before stimuli were presented. There were 5 calibration points used. The experimenter then attained a calibration and set the computer to present experimental stimuli. An observer sitting next to the experimenter recorded infant behavior live by watching the webcam view in Tobii Studio's Live Viewer. The experimenter coded for whether eyes were seen in the track status view (eyes seen: yes or no) and if infants were looking at stimuli (infant looking via Live Viewer: yes or no) for every SFM, RM, and test trial. Both the experimenter and observer took notes about any extra noise or disruptions over the course of the trials.

2.2 Results

Familiarization: Preliminary Analyses

Preliminary analyses for the familiarization trials were conducted to examine if the order of stimulus presentation (SFM first or RM first) or the shape infants viewed during SFM trials (cube or cylinder) had an effect on the means of total fixation duration or total number of fixations during the familiarization trials. No significant effects were found for either dependent variable.

Familiarization

The first set of analyses quantitatively examined whether infants looked differently at the two types of familiarization stimuli (SFM shape and RM stimuli). There were 35 infants (fourteen 3-5-month-olds and twenty-one 8-9-month-olds).

To examine visual scanning behavior of the younger infants, a repeated-measures ANOVA with Gender (male, female) as the between-subjects factor and Stimulus (SFM, RM) as the within-subjects factor was computed; the dependent measure was total fixation duration to the stimuli. Stimulus was calculated as a mean duration of looking across SFM stimuli and RM stimuli according to the number of trials each infant contributed. There were no significant results (see Table 1). A second similar repeated-measures ANOVA examined the dependent measure of total number of fixations made to the stimuli with no significant results.

To examine visual scanning behavior of the older infants, a repeated-measures ANOVA with Gender (male, female) as the between-subjects factor and Stimulus (SFM, RM) as the within-subjects factor was computed; the dependent measure was total fixation duration to the stimuli. Stimulus was calculated as a mean duration of looking across SFM stimuli and RM stimuli according to the number of trials each infant contributed. There were no significant results. A second similar repeated-measures

ANOVA examined the dependent measure of total number of fixations made to the stimuli with no significant results (see Table 1).

Table 1 *Raw familiarization data (mean and standard error) for Study 1 infants.*

		SFM *M* (SE)	RM *M* (SE)
Younger Infants	Total Fixation Duration (5 second stimuli)	2.14 (0.26)	2.33 (0.28)
	Total Number of Fixations	4.45 (0.67)	3.82 (0.44)
Older Infants	Total Fixation Duration (5 second stimuli)	2.00 (0.28)	1.93 (0.28)
	Total Number of Fixations	3.10 (0.33)	3.17 (0.29)

Test Analyses: Preliminary Analyses

Preliminary analyses for the test trials were conducted to examine if the order of stimulus presentation (sfm first or rm first), the shape infants viewed during block trials (cube or cylinder), the test order of stimulus presentation (novel stimulus on left first or stimulus on right first), and gender (male, female) had any effect on the novelty looking preferences during test trials. No significant effects were found for novelty test preferences (test 1 and test 2) for either dependent variable (total fixation duration and total number of fixations).

Test Analyses

The second set of analyses examined whether infants looked differently quantitatively to the two tests (test 1 and test 2) and the stimuli within those tests (novel shape, familiar shape). There were 35 infants (fourteen 3-5-month-olds and twenty-one 8-9-month-olds).

To examine the visual scanning behavior in the younger infants, novelty preference scores were calculated for the dependent variables total fixation duration and number of fixations, respectively. The preference scores were then tested against chance level using one sample t-tests. T-tests reveal that infants looked significantly at the novel SFM stimulus on test 1 in both total fixation duration and total number of fixation novelty preference scores; $t(13) = 5.21$, $p< .01$ and $t(13) = 3.21$, $p< .01$, respectively. No side preferences were found. No significant effects for looking were found on test 2 (see Table 2).

To examine the visual scanning behavior in the older infants, novelty preference scores were calculated for the dependent variables total fixation duration and total number of fixations, respectively. The preference scores were then tested against chance level using one sample t-tests. T-tests reveal that infants looked significantly to the novel SFM stimulus on test 1 in total fixation duration and trended to look to the novel SFM stimulus on test 1 in total number of fixation novelty preference scores; $t(11) = 2.27$, $p < .05$ and $t(11) = 1.93$, $p = .080$, respectively. No side preferences were found. No significant effects for looking were found on test 2 (see Table 2).

Table 2 *Test data (mean and standard error) for Study 1 infants.*

		Test 1 Novelty Preference Scores *M* (SE)	Test 2 Novelty Preference Scores *M* (SE)
Younger Infants	Fixation Duration	*0.80 (0.06)	+0.35 (0.08)
	Number of Fixations	*0.71 (0.07)	0.39 (0.08)
Older Infants	Fixation Duration	*0.73 (0.10)	+0.36 (0.08)
	Number of Fixations	+0.71 (0.11)	0.41 (0.08)

*p<.05, +p<.10

2.3 Discussion

The analyses suggest that both older and younger infants extracted shape from coherent motion and recognized the familiar object at test 1. The results for test 2 are less clear. In both infant age groups, a spurious trend (p<.10) for a familiarity preference at test 2 was found in the dependent variable of duration of looking (see Table 2). It is possible that after infants made the initial novelty preference at test 1, their shift of attention to the familiar object on test 2 reflects a deeper level of processing- the infants were perhaps scanning the familiar object further to assess the degree of similarity between it and the object viewed during familiarization. Further study is needed to examine this effect.

Another possibility is that infants are attending to the rotational axis of motion in addition to the shape information in the test trials. The present study had shapes' rotational axis presented during familiarization blocks match the shapes' rotational axis presented during test trials. Study 2 controlled for this test variable by presenting the familiar shape (seen during familiarization) rotating on a different axis during test trials, and presenting novel shape (not viewed during familiarization) rotating on the same axis as the familiar shape during test trials. The research question examined in the second study was whether infants will extract 3D shape in SFM displays with the added control for the axis of rotation within the stimuli.

3. STUDY 2

3.1 Method

Participants

Study 2 recruited 47 infants in the age ranges of 3-5 months (24 infants; 14 males and 10 females, mean age 5 months and 0 days) and 8-9 months (23 infants; 12 males and 11 females, mean age 9 months and 1 day). Study recruitment was the same process as described in Study 1.

Materials and Design

All stimuli were made using a graphical user interface. SFM and RM stimuli were formed as the stimuli in Study 1, with only two differences: The stimuli were composed of 768 (cube) and 904 (cylinder) white dots (equal densities) and the shape planes rotated 10° about a 3D x-axis during familiarization blocks. Each cube stimulus took up about 20% of the screen and each cylinder stimulus took up about 22% of the screen (screen size 51 x 32cm).

Presentation of familiarization stimuli to younger and older-aged infants was identical to Study 1, with only one difference during the familiarization trials: SFM and RM trial order (SFM presentation first within the block or RM presentation first within the block) was randomized (rather than alternating) and counterbalanced across subjects.

Since infants viewed repeated multiple trials of stimuli (young infants viewed 4 SFM stimuli and 4 RM stimuli; older infants viewed 2 SFM stimuli and 2 RM stimuli), Stimulus was calculated as a mean duration of looking across the SFM stimuli and the RM stimuli, respectively. For the younger sample SFM trial contribution, ten infants contributed 4 trials, ten infants contributed 3 trials, and four infants contributed 2 trials. For the younger sample RM trial contribution, eight infants contributed 4 trials, seven infants contributed 3 trials, five infants contributed 2 trials, and four infants contributed 1 trial. For the older sample SFM trial contribution, twenty infants contributed 2 trials and three infants contributed 1 trial. For the older sample RM trial contribution, nineteen infants contributed 2 trials and four infants contributed 1 trial.

Presentation of test stimuli to younger and older-aged infants was identical to Study 1, with only one difference during the test trials: the familiar shape rotated on the y-axis (novel axis) and the novel shape rotated on the x-axis (familiar axis). This allowed for the control and examination of parsing out shape and axis rotation of motion. Nineteen younger infants contributed to the test 1 trial and twenty-one younger infants contributed to the test 2 trial. Nineteen older infants contributed to the test 1 trial and twenty-two older infants contributed to the test 2 trial.

Procedure

The procedure was identical to that of Study 1.

3.2 Results

Familiarization: Preliminary Analyses

Preliminary analyses for the familiarization trials were conducted to examine if the shape infants viewed during SFM trials (cube or cylinder) had any effect on the means of total fixation duration or total number of times fixated during the familiarization trials. No significant effects were found.

Familiarization

The analyses that examined whether infants looked differently at the two types of familiarization stimuli (SFM shape and RM stimuli) were identical to those used in Study 1. There were 47 infants (twenty-four 3-5-month-olds and twenty-three 8-9-month-olds).

To examine the visual scanning behavior of the younger infants, a repeated-measures ANOVA with Gender (male, female) as the between-subjects factor and Stimulus (SFM, RM) as the within-subjects factor was computed; the dependent measure was total fixation duration. Stimulus was calculated as a mean duration of looking across SFM stimuli and RM stimuli according to the number of trials each infant contributed. There were no significant results. A second similar repeated-measures ANOVA examined the dependent measure of number of fixations made to the stimuli with no significant results (see Table 3).

To examine the visual scanning behavior of the older infants, a repeated-measures ANOVA with Gender (male, female) as the between-subjects factor and Stimulus (SFM, RM) as the within-subjects factor was computed; the dependent measure was total fixation duration. Stimulus was calculated as a mean duration of looking across SFM stimuli and RM stimuli according to the number of trials each infant contributed. There were no significant results. A second similar repeated-measures ANOVA examined the dependent measure of number of fixations made to the stimuli; results showed a significant Stimulus x Gender interaction; $F(1, 21) = 4.45$, p=.047. Follow-up comparisons revealed that females looked significantly more times to the RM stimulus than males, $t(12) = 2.196$, p=.044 (see Table 3).

Table 3 *Raw familiarization data (mean and standard error) for Study 2 infants.*

		SFM *M* (SE)	RM *M* (SE)
Younger Infants	Total Fixation Duration (5 second stimuli)	2.02 (0.21)	2.28 (0.24)
	Total Number of Fixations	4.87 (0.40)	4.58 (0.38)
Older Infants	Total Fixation Duration (5 second stimuli)	2.34 (0.26)	2.58 (0.25)
	Total Number of Fixations (males)	4.29 (0.55)	*3.58 (0.46)
	Total Number of Fixations (females)	4.59 (0.56)	*5.77 (0.88)

*p<.05 in paired comparisons between males and females

Test Analyses: Preliminary Analyses

Preliminary analyses for the test trials were conducted to examine if the shape infants viewed during block trials (cube or cylinder), the test order of stimulus presentation (novel stimulus on left first or novel stimulus on right first), and gender (male, female) had any effect on the novelty looking preferences during test trials. No significant effects were found for novelty test preferences at test 1. At test 2, however, novelty preferences for older infants showed a main effect of test order in total fxation duration and total number of fixations; $F(3, 21) = 10.081$, $p<.01$ and $F(3, 21) = 10.104$, $p<.01$, respectively. Since this main effect was found in both dependent variables examined, one sample t-tests examining older infants' novelty preferences at test 2 will be separated for those infants that viewed test order 1 (novel stimulus on left at test1 ; n=14) and those infants that viewed test order 2 (novel stimulus on right at test 1; n=8).

Test Analyses

The analyses that examined whether infants will look differently quantitatively to the two tests (test 1 and test 2) and the stimuli within those tests (novel shape, familiar shape) were identical to those used in Study 1. One sample t-tests revealed no significant results in either test trial (test 1 or test 2) for younger infants' novelty preference scores (see Table 4).

One sample t-tests revealed that older infants looked significantly at the novel SFM stimulus on test 1 in total fixation duration and trended to look longer at the novel SFM stimulus in total number of fixation novelty preference scores; $t(18) = 2.595$, $p<$

.05 and $t(21) = 1.88$, $p = .076$, respectively. No side preferences were found. In test 2, t-tests revealed that older infants with test order 1 (novel stimulus on right) looked significantly at the novel SFM stimulus in total fixation duration and total number of times fixated novelty preference scores; $t(13) = 3.908$, $p < .01$ and $t(13) = 4.303$, $p < .01$, respectively. These older infants also looked significantly more to the right side of the display on test 2 in both total fixation duration and total number of times fixated; $t(13) = 3.908$, $p < .01$ and $t(13) = 4.303$, $p < .01$, respectively. In test 2, t-tests revealed that older infants with test order 2 (novel stimulus on left) showed no novelty preferences and no side preferences (see Table 5).

Table 4 *Test data (mean and standard error) for Study 2 younger infants.*

	Test 1 Novelty Preference Scores *M* (SE)	Test 2 Novelty Preference Scores *M* (SE)
Fixation Duration	0.59 (0.07)	0.40 (0.09)
Number of Fixations	0.58 (0.07)	0.42 (0.08)

Table 5 *Test data (mean and standard error) for Study 2 older infants.*

	Test 1 Novelty Preference Scores *M* (SE)		Test 2 Novelty Preference Scores *M* (SE)
Fixation Duration	*0.70 (.08)	Fixation Duration (Novel on left first)	*0.79 (0.07)
		Fixation Duration (Novel on right first)	0.30 (0.12)
Number of Fixations	+0.65 (.08)	Number of Fixations (Novel on left first)	*0.77 (0.06)
		Number of Fixations (Novel on right first)	0.35 (0.12)

*p<.05, +p<.10

3.3 Discussion

The analyses showed that only the older infants in Study 2 extracted shape from coherent motion and recognized the familiar object at test. These infants looked longer to the novel shape presented at test 1, suggesting that they recognized the shape change even with the added component of the familiar shape rotating on a different axis. The younger infants, however, did not display a novelty preference. The change in rotational axis made the task of extracting shape in SFM stimuli more difficult.

4. GENERAL DISCUSSION AND CONCLUSION

The present research closely examined if infants are able to extract the 3D percept of shape in SFM stimuli. Both younger and older infants showed a novelty preference in Study 1, however, only the older infants displayed a novelty preference in Study 2. These results suggest not only that infants were attending to both the global shape presented in the SFM stimuli as well as the detailed component of the rotational axis of the stimuli, but also that adding the extra change in the component of rotational axis to SFM stimuli makes the task of extracting shape more difficult for infants. If, for example, infants only recognized the change in rotational axis, then they would have displayed a familiarity preference in test trials of Study 2. Neither sample of infants (younger or older), however, displayed this preference. Although younger infants in Study 2 did not reach significance, their patterns of looking during test 1 were similar to those of the older infants (see Tables 4 and 5). This also suggests that infants in both age groups were attending to both the percept of shape as well as the axis of rotation in the SFM stimuli.

As in all infant research, there were other developmental factors within these experiments which were not directly examined that may have made contributions to the results. One such factor is the development of binocular disparity, or stereoscopic depth perception. Generally the literature suggests that sensitivity to binocular disparity develops around 4 months (Fox, Aslin, Shea, & Dumais, 1980; Yonas, Arterberry, & Granrud, 1987). Yonas *et al.* (1987) found that infants at this age who did show binocular disparity sensitivity performed significantly better (displayed a novelty preference) on a 3D shape identification task than 4-month-old infants whom did not show binocular disparity sensitivity. These results were not clear cut, however, as half of the infants in the group designated as binocular disparity insensitive still showed a novelty shape preference at test. Furthermore, the authors suggest the possibility of other monocular cues the infants could have used in their shape discriminations at test, such as slight luminance or positioning differences in presentations.

A second developmental factor within the present experiments which may have made a contribution to the results is that of motion parallax. A monocular depth cue, motion parallax describes motion within the observer (rather than the stimulus) and arises when an observer's eye movements translate laterally (Nawrot, Mayo, & Nawrot, 2009). A recent longitudinal study in the infant literature suggests that this develops between 14-16 weeks, around the same time period as the development of binocular disparity (Nawrot *et al.*, 2009). The present experiments included infants in these age ranges (3-5 months), so there is a possibility that these developing perceptual abilities contributed to the results. However, these factors are probably not defining for two reasons. One, the sample of infants in the first study displayed a novelty shape preference. Secondly, the sample of infants in the second study which did not show a significant novelty shape preference had a mean age of 5 months, and were slightly older than those infants in the first study (mean age of 4 months and 22 days). Binocular disparity and motion parallax are estimated to develop around 4 months, and both samples of younger infants had mean ages above this (Fox *et al.*, 1980; Yonas *et al.*, 1987; Nawrot *et al.*, 2009). Furthermore, the procedures of the two studies were identical, with the infant sample in Study 2 being only slightly older, suggesting that the change in the SFM displays rather than the perceptual development of the infants was the factor for differential performance during test trials.

These findings contribute to the infant literature not only by furthering the understanding of infant shape perception, but also in the exploration of what kinds of information infants attend to in SFM displays. More specifically, both components of overall shape and rotational axis are important features infants attend to in SFM stimuli. Previous research found that 4-month-old infants discriminate structure in SFM stimuli, but that 2-month-old infants have more difficulty with these stimuli (Arterberry & Yonas, 1988; Arterberry & Yonas, 2000). Similar to these studies' results, young infants in Study 2 did not display a novelty shape preference when the familiar shape changed in rotational axis- a contributing component to the percept of shape in the SFM stimulus. The change in rotational axis made the shape percept less salient.

Like in adult perception of SFM stimuli, coherent motion is a key cue in the perception of SFM displays in infancy (Gilroy & Blake, 2004; Murray *et al.*, 2004; Tittle *et al.*, 1995; Arterberry & Yonas, 1988; Arterberry & Yonas, 2000). Within the SFM displays, there are a number of cues that infants may be using to extract information including both shape and axis of rotation. The present studies examined the effects of these cues on infant perception in SFM stimuli. This research contributes both to the field's understanding of 3D infant perception and infants' comprehension of their worlds.

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