MOTION PROCESSING AND FORM-FROM-APPARENT-MOTION IN INFANCY

A Dissertation

by

AMY HIRSHKOWITZ

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Chair of Committee,	Teresa Wilcox
Committee Members,	Gerianne Alexander
	Emily Davidson
	Carl Gabbard
Head of Department,	Paul Wellman

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ABSTRACT

Motion-carried information is a salient visual cue used in object perception to parse form in the optical array. The present research examined infants’ ability to extract form shapes in apparent motion stimuli, controlling for color and luminance information within the displays. In these form-from-apparent-motion (FFAM) displays, red “background” random dots are set against an overall white background, with a portion of the random dots set as green “foreground” dots. Although the dots do not move, the portion of the green-colored dots change over successive frames, giving an observer the impression that an object is moving. Infants in two age groups (11-13- and 14-18-month olds) were shown FFAM stimuli in familiarization/visual paired comparison (F/VPC) and discrimination paradigms. Infants in both paradigms extracted shape from apparent motion given luminance cues alone, and color and luminance cues co-varying; but failed to extract shape given color cues alone (Studies 1-2). Given only color cues, infants required denser random-dot displays to extract shape from apparent motion (Study 3). It is possible that both neural pathway separation between dorsal and ventral streams, as well as the ongoing development of edge-insensitive/edge-sensitive processing both play a role in the present results.

DEDICATION

To my family: Dad, Mom, and Abby

Always and forever

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1. INTRODUCTION: MOTION PROCESSING AND FORM-FROM-APPARENT-MOTION IN INFANCY

Object perception greatly depends on an individual's capacity to parse shapes in the optic array. One highly salient visual cue used both by infants and adults for recognizing shapes involves motion-carried information: it can be used to parse shapes in the absence of pictorial cue differences (such as luminance, color, or texture differences; e.g. in camouflage). For this reason, infant sensitivity to moving stimuli has been widely studied (Dobson & Teller, 1978; Dannemiller & Freedland, 1991; Wattam-Bell, 1992; Banton & Bertenthal, 1996; Dobkins et al., 2006; Wattam-Bell, 2009; see Braddick & Atkinson, 2011 for a review). Additionally, much previous research indicates that young infants use common, rigid motion to parse shapes when presented with occluded stimuli (processes involving object unity); to recognize whole, three-dimensional objects (i.e., processes involving object completion); and even to recognize continuous object trajectories (i.e., processes involving spatiotemporal completion) (Kellman & Spelke, 1983; Johnson, 2004; Soska & Johnson, 2008; Johnson, 2010). Considerable research focuses on facilitative effects of common, rigid motion for parsing shapes and objects during infancy; however, less is known about the effects of apparent motion in shape perception: the motion individuals perceive in stationary stimuli.

1.1 Previous Research

Infants are sensitive to motion-carried information early in development, with capacity increasing over time and with experience (Braddick & Atkinson, 2011). At one-month, optokinetic nystagums (OKN; automatic eye movements) to patterns undergoing directional motions are present, as well as sensitivity to perceived motion expansion (Bower, Broughton, & Moore, 1970; Nanez & Yonas, 1994; Braddick & Atkinson, 2011). At age 2-3 months, infants can detect motion direction, motion velocity, local motion, global motion, and discriminate between different types of motion (Wattam-Bell, 1992; Dobkins & Teller, 1996; Banton, Dobkins, & Bertanthal, 2001; Kellman & Arterberry, 2006; Blumenthal et al., 2013).

Young infants also use motion-carried information to extract two-dimensional (2D) shape, and a growing body of evidence indicates that motion-carried information facilitates 2D shape perception, even in the absence of clearly defined contour information (i.e. illusory contours; Johnson & Aslin, 1996; Curran et al., 1999; Johnson & Mason, 2002; Otsuka & Yamaguchi, 2003; Kavsek & Yonas, 2006). For example, Johnson and Mason (2002) found that 2-month-old infants extract shape given rigid motion cues in sparse random dot displays. Using Kanizsa figures, Otsuka and Yamaguchi (2003) found that only older 7-8-month old infants preferred to look at a static figure with illusory contours over a static figure without illusory contours, however, with the addition of kinematic information younger 3-4- and 5-6-month olds reliably preferred to look at the illusory square undergoing motion. Kavsek and Yonas

(2006) likewise found that 4-month-old infants preferred to look at a display with rigid motion for illusory contour over a display with rigid motion without an illusory contour.

Less is known about how infants use apparent motion for parsing shapes. Apparent motion refers to an individual's perception of motion when the object is stationary. One example of apparent motion is flicker (i.e., lights flashing on and off in sequence making it appear that the light is moving). Flicker, a low-level stimulus defined solely by luminance cues, is a popular vehicle for exploring infant perception using a preference paradigm (i.e. where infant directs more attention to one display compared to another). Flicker can be used to determine critical flicker frequency (CFF); the speed at which a light going on and off can no longer be distinguished from a light that is on continuously. Studies investigating infant CFFs suggest that infants reach similar CFFs to adults around 8 weeks. Interestingly, Farzin and associates (2011) found infants as young as 6 months could successfully detect high contrast flicker (0.42 at 10 Hz); however, infants' performance in flicker segmentation (distinguishing between individual flickers) was much more limited. Only the older 12- and 15-month-old infants individuated out-of-phase square flicking at 1HZ. These results suggest that although infant sensitivity to flicker develops early, temporal resolution for attention develops much more slowly.

These results from flicker research may have an important bearing on shape processing in apparent motion studies with infants. While common motion may facilitate shape processing early in infancy, it is possible that integration, like individuation, of apparent motion processing develops more slowly.

It is possible to incorporate both apparent motion and 2D shape by displaying computer-generated dots on a screen that undergo color and luminance changes. Adult studies use these types of stimuli arrays (Cicerone et al., 1995; Cicerone & Hoffman, 1997). These random-dot stimuli are usually set against a white background. The random dots in these stimuli remain stationary, however, a portion of the dots in the form of a shape change in color and/or luminance over successive frames. Typically, the colors of red and green are used so that when viewed, an observer has the percept of a green disk moving back and forth in a sea of red dots (see Figure 1). This is defined as apparent motion because the dots remain stationary and the motion is illusory; that is, it is defined by the dot changes in color. The behavioral literature with adults suggests that adults perceive the apparent motion and illusory shape contours even in conditions with no change in luminance (Chen & Cicerone, 2002). As luminance differences between background and foreground in chromatic stimuli diminish, contour becomes more difficult to perceive. Although color is not created from the motion in the stimuli (there is no actual motion present), these stimuli are called *color-from-motion* in the adult literature. The term color-from-motion is a confusing misnomer and the paradigm might be more accurately described as *form-from-apparent-motion-of-color* (FFAMC). Although the adult behavioral literature is well established (Cicerone et al., 1995; Cicerone & Hoffman, 1997; Fidopiastis et al., 2000; Prophet, Hoffman, & Cicerone, 2001; Chen & Cicerone, 2002), to date only one published paper has used FFAMC with infants.

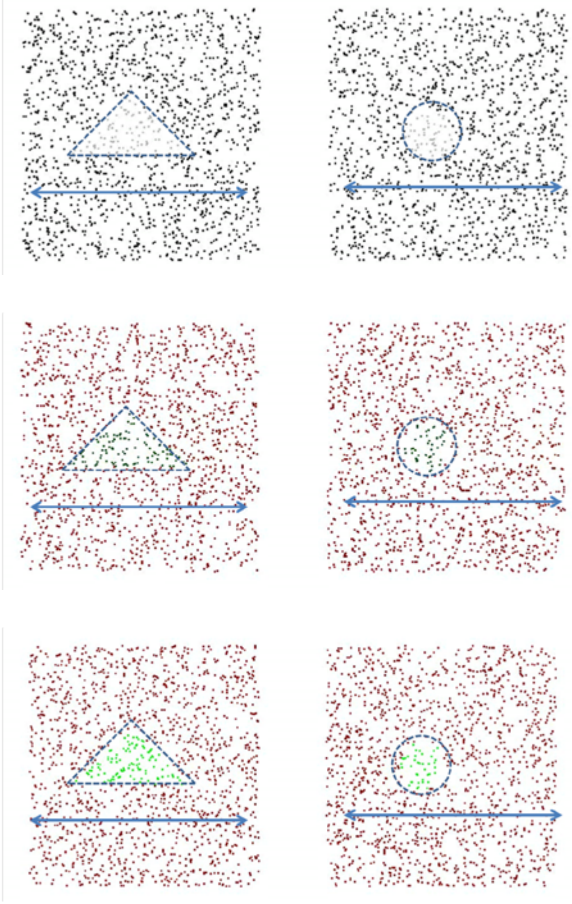

Figure 1. Stimuli used in Study 1. Conditions (top to bottom): FFAM-LD, FFAM-CD, FFAM-CLD. Dotted contours not present in actual stimuli. Note: Form-From-Apparent-Motion (FFAM); Luminance Differences (LD); Color Differences (CD); Color and Luminance Differences (CLD).

In a series of studies, Yamaguchi, Kanazawa, and Okamura (2008) used 2D random-dot stimuli to test infant sensitivity to contour with apparent motion. Infants between the ages of 3-8 months were presented with what the authors termed a subjective-contour-from-apparent-motion (SCAM) stimulus. These stimuli parameters were similar to the FFAMC stimuli used in the adult literature, with the exception that SCAM stimuli differed in both color (red-green) and luminance (brightness), so that the red and green colors stood out from one another and created a strong shape contour percept when viewed with the apparent motion. Non-SCAM stimuli, in contrast, were those in which the red and green random dots were equiluminant. Using the preferential looking technique, the authors compared a SCAM stimulus to a non-SCAM stimulus. Results suggested that the older infants (5-6 months and 7-8 months) perceived the visible contour but younger infants (3-4 months) showed no preference. The preference was also not achieved when the stimuli were presented statically. When the authors employed sparse random-dot SCAM and non-SCAM stimuli (i.e. contour information was unavailable) as further test of contour perception, however, infants still showed a preference for sparse SCAM stimuli. It is possible that this preference reflects one for higher luminance contrast. To determine the role (or necessity) of luminance differentials in infancy will require further research.

1.2 Present Research

The present research further investigated the role of apparent motion 2D infant shape perception by utilizing FFAMC stimuli. As noted by Yamaguchi et al. (2008), perceiving FFAMC requires both chromatic and luminance temporal contrast sensitivity. The extant literature suggests that infants have such sensitivities by 2-3 months of age (Rasengane, Allen, & Manny, 1996; Dobkins & Teller, 1996a; Dobkins & Teller, 1996b; Teller, 1998; Pereverzeva et al., 2002). The present research used a familiarization paradigm with a test phase to examine whether infants will extract 2D shape in FFAMC displays. This paradigm was successfully used previously to examine extraction of shape with younger infants in our lab (Hirshkowitz & Wilcox, 2013). However, since this familiarization paradigm has yet been unused with these stimuli, and the literature is mixed concerning when motion mechanisms are fully developed (Ellemberg et al., 2003; Armstrong, Maurer, & Lewis, 2009; Farzin et al., 2011; Manning et al., 2012; Blumenthal et al., 2013) the current infant sample is older (age range = 11-18 months). Specifically, the goal was to determine whether color is sufficient for object recognition of 2D shapes or whether luminance contrast is also necessary in FFAMC. To this end, three conditions were devised:

1. An achromatic condition defined only by luminance contrast (*termed form-from-apparent-motion with luminance differences FFAM-LD*)
2. A color-only condition (red-green) in which random dots' luminance's will be held constant and only color changed (*termed form-from-apparent-motion with color differences, FFAM-CD*)
3. A color + luminance condition in which random dots will be varied in both color (red-green) and luminance *(termed form-from-apparent-motion with color and luminance differences, FFAM-CLD).*

2. STUDY 1

2.1 Method

2.1.1 Participants

Seventy-three infants were tested (n; Caucasian = 56; Black/African American = 1; Hispanic = 7; Asian = 6; Other/mixed race = 3). Two age groups were studied. The younger infant group included thirty-six 11-13 month-old infants (Younger, mean age = 12 months, 24 days; 22 females and 14 males; conditions FFAM-LD, n = 12; FFAM-CD, n = 12; and FFAM-CLD, n =12) and the older group included thirty-seven 14-18 month-old infants (Older, mean age = 15 months, 29 days; 22 females and 15 males; conditions FFAM-LD, n = 12; FFAM-CD, n = 13; and FFAM-CLD, n =12). Thirty-seven additional infants were tested and excluded due to a history of colorblindness in the family (n = 9), prematurity (n= 6), fussiness (n = 20), or technical malfunction (n = 2).

Infants and parents were recruited primarily through commercially produced lists. Letters about the study were mailed, and phone calls were 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. The parents were offered a lab T-shirt or $5 for participation. Informed consent, including the explanation of experimental procedure, was obtained prior to testing.

2.1.2 Apparatus and Data Recording

A remote eye tracker (Tobii T60 XL) with an infrared corneal reflection mechanism to detect pupil position of both eyes (embedded into the monitor) was used to measure eye movements during stimuli presentation. The eye-tracker monitor is a 24 in flat screen (17.7W TFT l flat screen monitor) with a resolution of 1024 x 768 pixels set to 32-bit color. The Tobii T60 XL records data at 60 Hz with an average accuracy of 0.5 degree visual angle and a head movement compensation drift of **G**0.1. The monitor was mounted on an adjustable arm so that it is positioned optimally for each infant. A Logitech Webcam Pro 9000 was placed directly below the monitor to record a full-face view of the infant during stimuli presentation. The stimuli were presented using professional visualization software (Tobii Studio) on a Dell Precision desktop computer with a Windows 7 operating system.

2.1.3 Stimuli

All stimuli were made using a customized graphical user interface (GUI). Stimuli were composed of 1500 random dots (FFAM-LD condition black, FFAM-CD condition red, and FFAM-CLD condition red; $x, y, cd/m^2$: 0.23, 0.28, 0.42; 0.50, 0.45, 17; 0.50, 0.45, 17 respectively) against a white background on a 480 x 480 pixel display. Two-dimensional shapes (circle or triangle) were composed of 46 random dots (FFAM-LD condition grey, FFAM-CD condition green, FFAM-CLD condition green; $x, y, cd/m^2$: 0.26, 0.4, 124; 0.13, 0.65, 17; 0.23, 0.65, 140 respectively) within each stimulus frame of the display. Stimulus displays moved at a rate of 10 f/s horizontally across the display for a total of 5 seconds.

2.1.5 Design

Each infant was placed in one of three stimulus conditions:

1. ***FFAM-LD: Form-From-Apparent-Motion with Luminance Difference.*** Achromatic stimuli were presented as black background dots and grey foreground shape dots in apparent motion across the display; background and foreground dots differed in luminance without color information
2. ***FFAM-CD: Form-From-Apparent-Motion with Color Difference.*** Stimuli were presented as red background dots and green foreground shape dots in apparent motion across the display; background and foreground dots were of differing colors and equal luminance
3. ***FFAM-CLD: Form-From-Apparent-Motion with Color and Luminance Difference.*** Stimuli were presented as red background dots and green foreground shape dots in apparent motion across the display; background and foreground dots differed in both color and luminance

All infants were tested in a familiarization/visual paired comparison (F/VPC) paradigm. This paradigm has been employed successfully previously in our lab using random-dot visual stimuli (Hirshkowitz & Wilcox, 2013). Infants viewed four 5-second familiarization trials with one 2D shape stimulus moving along the horizontal plane (see Figure 1). Two-dimensional shape presentations were counterbalanced: half the infants saw a circle stimulus during the familiarization trials; the other half saw a triangle stimulus during the familiarization trials. After familiarization, infants were exposed to a 5-second test trial. The test trial depicted the familiar stimulus array (shape seen during familiarization) and a novel stimulus array (other shape) moving along the horizontal plane side-by-side. The side on which the familiar and novel shape was presented was counterbalanced across infants.

2.1.6 Procedure

Infants were seated in a parent's lap or in a booster seat (with the parent sitting beside the infant) 65 cm away from the monitor on which the stimuli were presented. The testing room was dark and black curtains surrounded the infant/parent. Parents were given painted sunglasses to wear during the test session. If parents were uncomfortable wearing the sunglasses, they were asked to close their eyes for the test session. To obtain reliable and valid eye movement data the Tobii Studio infant calibration program was used prior to stimulus presentation. Animated stimuli were used to direct attention to five gaze positions which cover over 80% of the viewing area.

2.1.7 Data Coding

Total duration of fixations to familiarization and test trial stimuli will be coded. Fixation data were defined using the Tobii fixation filter (version 2.2.8) with a velocity threshold of 35 pixels and a distance threshold of 35 pixels. Total duration of looking during each trial was calculated by the sum of fixation data for each trial.

2.2 Results

2.2.1 Preliminary Analyses

Two 2x2 ANOVAs with between subjects factors of *Gender* (Male, Female) and *Shape Viewed During Familiarization* (Circle, Triangle) was computed for the mean of total duration of fixations across the 4 familiarization trials (familiarization phase) and the novelty preference of total looking duration (test phase). These analyses revealed no significant main effects or interactions. Hence, these factors were removed from further analysis.

2.2.2 Familiarization Analyses

To examine the looking behavior of infants during the familiarization trials, the mean across the 4 familiarization trials was computed for total duration of fixations (see Table 1). A 2x2 ANOVA with the between subjects factors of *Age Group* (Younger, Older) and *Stimulus Condition* (FFAM-LD, FFAM-CD, and FFAM-CLD) was conducted with mean of total duration of fixations across the 4 familiarization trials. This ANOVA revealed a main effect for *Stimulus Condition,* F (1, 67) = 7.34, $p < 0.05$, $\eta_p^2 = 0.180$. Pairwise comparisons revealed that infants looked significantly longer in the FFAM-LD condition than the FFAM-CD condition, ($p = 0.01$); and that infants looked significantly longer in the FFAM-CLD condition than in the FFAM-CD condition ($p = 0.001$). No significant results were found for *Age Group* or *Stimulus Condition x Age Group,* F (1, 67) = 0.35 and F (1, 67) = 0.01, respectively.

An additional analysis was conducted to assess the looking behavior of infants during the familiarization trials using the dependent variable of total number of fixations (see Table 2). The same pattern of results was obtained in this data as in the total duration of fixations data.

Age Group	Condition		
	FFAM-LD M (SD)	FFAM-CD M (SD)	FFAM-CLD M (SD)
11-13 month-olds	3.04 (0.87)	2.29 (1.02)	3.29 (1.27)
14-18 month-olds	3.14 (0.85)	2.42 (0.74)	3.45 (0.94)

Table 1. Total fixation duration of Study 1 familiarization trials. Means and standard deviations are shown in table.

Age Group	Condition		
	FFAM-LD M (SD)	FFAM-CD M (SD)	FFAM-CLD M (SD)
11-13 month-olds	3.04 (0.74)	3.81 (1.53)	4.90 (2.30)
14-18 month-olds	4.79 (2.33)	3.29 (0.91)	4.90 (3.10)

Table 2. Total number of fixations of Study 1 familiarization trials. Means and standard deviations are shown in table.

2.2.3 Test Analyses

To examine the looking behavior of infants in the test trial, a novelty preference score was calculated from the looking duration data (see Table 3). The dependent variable examined was the total duration of fixations to each test stimulus. The novelty preference score was calculated as:

$$\textbf{\textit{Novelty Score}} = \frac{\textbf{\textit{Looking to the Novel Stimulus}}}{\textbf{\textit{Looking to the Novel Stimulus + Looking to the Familiar Stimulus}}}$$

A 2x3 ANCOVA was conducted with between-subjects factors of *Age Group* (Younger and Older) and *Stimulus Condition* (FFAM-LD, FFAM-CD, and FFAM-CLD) with the dependent measure of the novelty preference of total looking duration, and the mean total looking duration during familiarization trials as the covariate. As there was a significant effect of condition found in the familiarization phase, the familiarization data was used as a covariate to adjust for group differences in looking prior to the test trial. No significant effects were found for *Age Group* or *Stimulus Condition x Age Group*, F (1, 66) = 0.001 and F (1, 66) = 0.06, respectively. The analysis revealed a main effect for *Stimulus Condition*, F (1, 66) = 3.54, $p < 0.05$, $\eta_p^2 = .097$. Pairwise comparisons revealed that the novelty preference score was significantly higher in the FFAM-LD condition than the FFAM-CD condition, ($p = 0.02$); and that the novelty preference score was significantly higher in the FFAM-CLD condition than in the FFAM-CD condition (p = 0.024). . One samples t-tests with the novelty preference score set at chance (.5) revealed infants in both FFAM-LD and FFAM-CLD conditions looked significantly to the novel shape, *t*(23) = 2.98, *p* < .01 and *t*(23) = 3.40, *p* < .01, respectively. Infants in the FFAM-CD condition did not look to the novel shape above chance *t*(24) = 0.23, *p* > .05. This analysis confirmed that infants in the FFAM-LD and FFAM-CLD conditions displayed significant novelty preferences.

An additional analysis was conducted to assess the looking behavior of infants during the test trials using the dependent variable of total number of fixations (see Table 4). The same pattern of results was obtained in this data as in the total duration of fixations data.

	Condition		
Age Group	FFAM-LD M (SD)	FFAM-CD M (SD)	FFAM-CLD M (SD)
11-13 month-olds	0.67 (0.34)	0.50 (0.27)	0.65 (0.30)
14-18 month-olds	0.67 (0.21)	0.48 (0.26)	0.68 (0.17)

Table 3. Novelty percentage using total fixation duration of Study 1 test trials. Means and standard deviations are shown in table.

Age Group	Condition		
	FFAM-LD M (SD)	FFAM-CD M (SD)	FFAM-CLD M (SD)
11-13 month-olds	0.61 (0.35)	0.57 (0.20)	0.66 (0.29)
14-18 month-olds	0.61 (0.24)	0.48 (0.26)	0.64 (0.17)

Table 4. Novelty percentage using total number of fixations of Study 1 test trials. Means and standard deviations are shown in table.

2.3 Discussion

Analyses found that both age groups (11-13 months, 14-18 months) of infants displayed a novelty shape preference in the FFAM-LD and FFAM-CLD conditions during the test phase. This novelty preference suggests that infants extracted the initial shape seen during the familiarization phase, remembered that shape, and found the novel shape viewed during test trials more interesting. However, the same pattern was not found in the FFAM-CD condition. This main effect of condition held, even when familiarization data were used as a covariate to adjust for group differences.

These data suggest that infants utilized luminance information in the apparent motion displays to extract 2D shape. This effect held both in the presence and in the absence of co-variation between color and luminance cues. These results suggest one of two possibilities:

(1) the infants in the FFAM-CD condition did not remember the 2D shape viewed in familiarization trials and were unable to compare the two shapes between familiarization trials and test trials or

(2) the infants in the FFAM-CD were unable to discriminate between the 2D shapes presented in the test trial, and thus could not extract the shape.

Studies 2 and 3 were designed to address these two possibilities. These studies used a discrimination paradigm in which infants were presented apparent motion displays both with and without the presence of a 2D shape. Infants viewed an apparent motion display and a formless dot display side-by-side simultaneously. Study 2 directly tested whether memory was the key factor in infants' preferences for shape stimuli. Unlike in study 1 with both familiarization and test phases, study 2 only had a test phase in which infants were presented with apparent motion shape stimuli and formless apparent motion side-by-side. I hypothesized that if infants perceive the 2D shape in the apparent motion displays, they should prefer to look at the display with shape defined by apparent motion over the formless dot display.

3. STUDY 2

3.1 Method

3.1.1 Participants

Sixty infants were tested (n; Caucasian = 44; Hispanic = 6; Asian = 8; Other/mixed race = 2). Two age groups were studied. Sixty infants in the age ranges of 11-13 months (Younger, mean age = 12 months, 10 days; 13 females and 17 males; conditions FFAM-LD/FLAM-LD, n = 10; FFAM-CD/FLAM-CD, n = 10; and FFAM-CLD/FLAM-CLD, n =10) and 14-18 months (Older, mean age = 16 months, 22 days; 14 females and 16 males; conditions FFAM-LD/FLAM-LD, n = 10; FFAM-CD/FLAM-CD, n = 10; and FFAM-CLD/FLAM-CLD, n =10) were tested. Thirty-four additional infants were tested and excluded due to a history of colorblindness in the family (n = 9), fussiness (n = 20), or technical malfunction (n = 4). Recruitment was the same as described in study 1.

3.1.2 Apparatus and Data Recording

The apparatus and data recording were the same as described in study 1.

3.1.3 Stimuli

The 2D shape apparent motion stimuli parameters were identical to those reported in study 1 for each of the three conditions (FFAM-LD, FFAM-CD, and FFAM-CLD). Formless dot display stimuli were also constructed using the same customized GUI. All parameters in the formless dot display stimuli were identical to the 2D shape apparent motion stimuli, save for one: rather than the 46 random dots within each stimulus frame moving as a clustered 2D shape (circle, triangle) along the horizontal plane, the 46 random dots changing in luminance or color within each stimulus frame changed in a random fashion. This random change in luminance or color over the entire stimulus array appeared as a twinkling in the entire random-dot stimulus (see Figure 2).

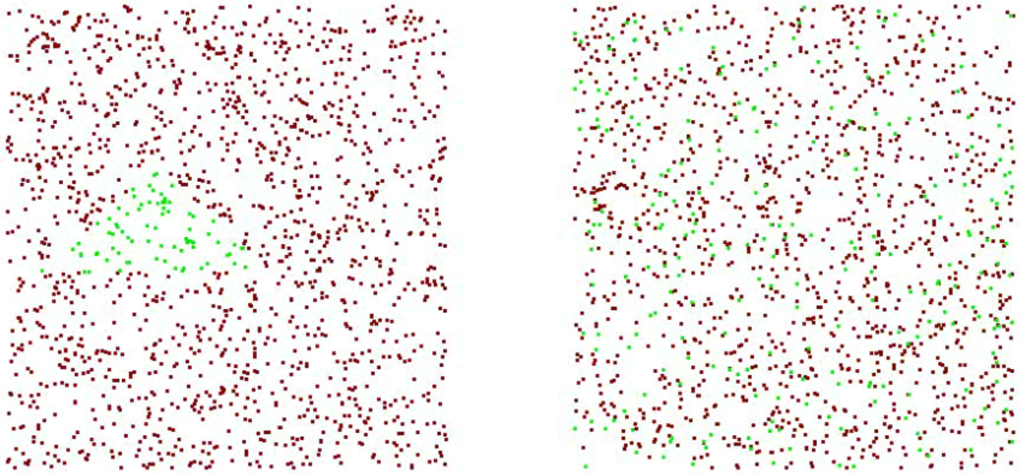

Figure 2. Stimuli used in Study 2. Stimuli: FFAM-CLD (left panel) /FLAM-CLD (right panel) condition. Note: Form-From-Apparent-Motion (FFAM); Color and Luminance Differences (CLD); Formless Apparent Motion (FLAM).

3.1.4 Design

Each infant was placed in one of three stimulus conditions***:***

1. ***FFAM-LD vs. FLAM-LD: Form-From-Apparent-Motion with Luminance Difference vs. Formless Apparent Motion- Luminance Difference.*** Achromatic stimuli were presented as black background dots and grey foreground shape or twinkling dots in apparent motion across the display

2. ***FFAM-CD vs. FLAM-CD: Form-From-Apparent-Motion with Color Difference vs. Formless Apparent Motion- Color Difference.*** were presented as red background dots and green foreground shape or twinkling dots in apparent motion across the display; background and foreground dots were of equal luminance

3. ***FFAM-CLD vs. FLAM-CLD: Form-From-Apparent-Motion with Color and Luminance Difference vs. Formless Apparent Motion- Color and Luminance Difference.*** Stimuli were presented as red background dots and green foreground shape or twinkling dots in apparent motion across the display; background and foreground dots differed in luminance

All infants were tested in a discrimination paradigm. Infants viewed 2 trials of FFAM and FLAM stimuli side-by-side. Each infant was placed into one 2D shape presentation condition (circle or triangle). Both trials lasted 5 seconds. Side presentation of FFAM and FLAM stimuli was counterbalanced by Tobii Studio, and side of presentation was reversed after T1.

3.1.5 Procedure

The procedure was identical to that described in proposed Study 1. Infants viewed discrimination stimuli on a Tobii T60XL.

3.1.6 Data Coding

Total duration of fixations to each FFAM and FLAM stimulus were examined. Fixation data were defined with the same parameters as described in Study 1. Total duration of fixations to each FFAM and FLAM stimulus was coded for each trial.

3.2 Results

3.2.1 Preliminary Analyses

A 2x2 repeated-measures ANOVA with a between subjects factor of *Gender* (Male, Female) and within-subjects factor of *Trial* (1, 2) was computed for the mean duration of looking to the shape stimulus. A second 2x2 repeated-measures ANOVA with between subjects factor of *Shape* (Circle, Triangle) and within-subjects factor of *Trial* (1, 2) was computed for the mean duration of looking to the shape stimulus. Both analyses revealed no significant main effects or interactions. Hence, these factors were removed from further analysis.

3.2.2 Main Analyses

To examine the behavior of infants in the discrimination trials, a shape preference score was calculated using mean duration of looking (see Table 5). The dependent variable examined was the total duration of fixations to each trial stimulus. The shape preference score was calculated as:

$$\textbf{\textit{Shape Preference}} = \frac{\textbf{\textit{Looking to the FFAM Stimulus}}}{\textbf{\textit{Looking to the FFAM Stimulus + Looking to the FLAM Stimulus}}}$$

A 2x3 ANOVA with the between subjects factors of *Age Group* (Younger, Older) and *Stimulus Condition* (FFAM-LD/FLAM-LD, FFAM-CD/FLAM-CD, and FFAM-CLD/FLAM-CLD) was conducted on mean of total duration of fixations to the FFAM Stimulus (2D shape score) across the 2 discrimination trials. Data reveal a main effect for *Stimulus Condition*, F (1, 52) = 4.11, $p < 0.05$ $\eta_p^2 = 0.136$. Pairwise comparisons revealed that the shape score was significantly higher in the FFAM-LD condition than the FFAM-CD condition, (p = 0.013); and that the shape score was significantly higher in the FFAM-CLD condition than in the FFAM-CD condition (p = 0.02). One samples t-tests with the novelty preference score set at chance (.5) revealed infants in both FFAM-LD and FFAM-CLD conditions looked significantly to the novel shape, $t(19) = 2.58$, $p < .05$ and $t(19) = 3.70$, $p < .01$, respectively. Infants in the FFAM-CD condition did not look to the novel shape above chance $t(19) = 0.33$, $p > .05$.

An additional analysis was conducted to assess the looking behavior of infants during the test trials using the dependent variable of total number of fixations (see Table

6). The same pattern of results was obtained in this data as in the total duration of fixations data.

Age Group	Condition		
	FFAM-LD M (SD)	FFAM-CD M (SD)	FFAM-CLD M (SD)
11-13 month-olds	0.73 (0.27)	0.52 (0.22)	0.58 (0.15)
14-18 month-olds	0.58 (0.22)	0.48 (0.14)	0.70 (0.18)

Table 5. Shape percentage using total fixation duration of Study 2 trials. Means and standard deviations are shown in table.

Age Group	Condition		
	FFAM-LD M (SD)	FFAM-CD M (SD)	FFAM-CLD M (SD)
11-13 month-olds	0.70 (0.20)	0.51 (0.20)	0.60 (0.16)
14-18 month-olds	0.62 (0.18)	0.50 (0.11)	0.67 (0.21)

Table 6. Shape percentage using total number of fixations of Study 2 trials. Means and standard deviations are shown in table.

3.3 Discussion

Study 2 allowed us to further examine infant 2D shape processing via a discrimination paradigm. Infants in the FFAM-LD/FLAM-LD and FFAM-CLD/FLAM-CLD conditions had a significantly longer duration of fixations to the shape stimuli over the formless random dot apparent motion stimuli. Similar to study 1, this result was not found in the FFAM-CD/FLAM-CD condition: infants in this condition looked equally between the two displays. These results suggest that infants in the FFAM-LD/FLAM-LD and FFAM-CLD/FLAM-CLD conditions perceived the 2D shape in apparent motion, but that infants in the FFAM-CD/FLAM-CD condition did not.

The use of a discrimination paradigm in this study eliminated the possibility that infants might fail to exhibit a shape preference because of a memory difficulty. Rather, the infants in the FFAM-CD/FLAM-CD condition did not discriminate between an apparent motion shape and formless apparent motion in the absence of luminance differences. This result was similar to that in study 1, which found that infants in the FFAM-CD condition did not display a shape novelty preference. Previous research indicates that infants at this age not only discriminate between colors, but also use color information for object individuation (Teller, 1998; Pereverzeva et al., 2002; Dobkins, 2009; Wilcox, 1999; Woods & Wilcox, 2010). Could it be possible for infants to show a shape preference given more supportive conditions? Study 3 examined this question by holding color constant and providing more information in the stimuli. It is possible that providing additional information could facilitate a shape percept, given only color differences. Thus, Study 3 examined this question in further detail by employing the use of the discrimination paradigm, but with denser dot displays in the FFAM-CD/FLAM-CD and FFAM-LD/FLAM-LD conditions. This study directly examined if denser displays facilitated significantly more scanning in the FFAM display, evidence for the 2D shape percept.

4. STUDY 3

4.1 Method

4.1.1 Participants

Forty infants were tested (n; Caucasian = 30; Hispanic = 2; Asian = 5; Other/mixed race = 3). Two age groups were studied. Forty infants in the age ranges of 11-13 months (Younger, mean age = 12 months, 27 days; 10 females and 10 males; conditions FFAM-LD/FLAM-LD, n = 10; FFAM-CD/FLAM-CD, n = 10) and 14-18 months (Older, mean age = 16 months, 2 days; 9 females and 10 males; conditions FFAM-LD/FLAM-LD, n = 10; FFAM-CD/FLAM-CD, n = 10) were tested. Twenty-two additional infants were tested and excluded due to a history of colorblindness in the family (n = 7), prematurity (n = 1) fussiness (n = 12), or technical malfunction (n = 2). Recruitment was the same as described in study 1.

4.1.2 Apparatus and Data Recording

The apparatus and data recording were the same as described in Study 1.

4.1.3 Stimuli

The 2D shape apparent motion stimuli parameters were identical to those reported in proposed Study 2 for the FFAM-LD/FLAM-LD and FFAM-CD/FLAM-CD conditions, save for one: the number of dots in the display was multiplied tenfold. In both displays, there were 15,000 dots overall, with 460 dots changing color in each stimulus frame (see Figure 3). In the FFAM-LD and FFAM-CD stimuli, the 460 dots composed a 2D shape (circle or triangle) moving along the horizontal plane; in the FLAM-LD and FLAM-CD stimuli, the 460 dots were formless and resemble twinkling.

4.1.4 Design

All infants were tested in a discrimination paradigm, in the dense dot FFAM-CD/FLAM-CD displays. Infants viewed 2 trials of FFAM-CD/FLAM-CD or FFAM-LD/FLAM-LD stimuli side-by-side. Each infant was placed into one 2D shape presentation (circle or triangle). Both trials lasted 5 seconds. Side presentation of FFAM and FLAM stimuli was counterbalanced by Tobii Studio and side of presentation was reversed after T1.

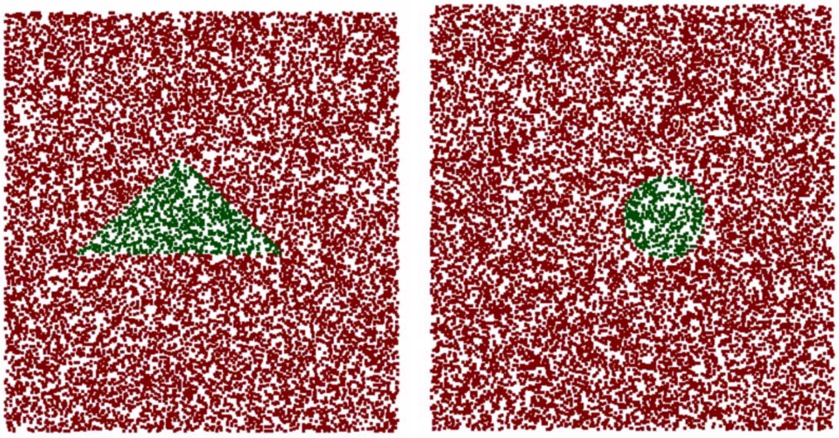

Figure 3. Stimuli used in Study 3. FFAM-CD/FLAM-CD stimuli shown. Note: Form-From-Apparent-Motion (FFAM).

4.1.5 Procedure

The procedure was identical to that described in Study 1. Infants viewed discrimination stimuli on a Tobii T60XL.

4.1.6 Data Coding

Data coding was identical to that in Study 2.

4.2 Results

4.2.1 Preliminary Analyses

A 2x2 repeated-measures ANOVA with a between subjects factor of *Gender* (Male, Female) and within-subjects factor of *Trial* (1, 2) was computed for the mean duration of looking to the shape stimulus. A second 2x2 repeated-measures ANOVA with between subjects factor of *Shape* (Circle, Triangle) and within-subjects factor of *Trial* (1, 2) was computed for the mean duration of looking to the shape stimulus. Both analyses revealed no significant main effects or interactions. Hence, these factors were removed from further analysis.

4.2.2 Main Analyses

As in Study 2, a shape preference score was calculated from the looking duration data (see Table 7). The dependent variable examined was the total duration of fixations to each trial stimulus. The shape preference score was calculated as:

$$\textbf{\textit{Shape Preference}} = \frac{\textbf{\textit{Looking to the FFAM Stimulus}}}{\textbf{\textit{Looking to the FFAM Stimulus + Looking to the FLAM Stimulus}}}$$

A 2x2 ANOVA with the between subjects factors of *Age Group* (Younger, Older) and *Stimulus Condition* (FFAM-LD/FLAM-LD, FFAM-CD/FLAM-CD, and FFAM-CLD/FLAM-CLD) was conducted on mean of total duration of fixations to the FFAM Stimulus (2D shape score). The results revealed no significant main effects or interactions. One samples t-tests with the mean total duration of fixations to the FFAM Stimulus (across the 2 trials) set at chance (.5) revealed infants in both FFAM-LD/FLAM-LD and FFAM-CD/FLAM-CD conditions looked significantly more to the 2D shape than the formless display, $t(19) = 2.26$, $p < .05$ and $t(19) = 2.57$, $p < .05$, respectively. This suggests that infants in both conditions extracted the 2D shape in the denser apparent motion displays.

An additional analysis was conducted to assess the looking behavior of infants during the test trials using the dependent variable of total number of fixations (see Table 8). The same pattern of results was obtained in this data as in the total duration of fixations data.

Age Group	Condition	
	FFAM-LD M (SD)	FFAM-CD M (SD)
11-13 month-olds	0.65 (0.26)	0.68 (0.23)
14-18 month-olds	0.59 (0.20)	0.55 (0.15)

Table 7. Shape percentage using total fixation duration of Study 3 trials. Means and standard deviations are shown in table.

Age Group	Condition	
	FFAM-LD M (SD)	FFAM-CD M (SD)
11-13 month-olds	0.65 (0.23)	0.72 (0.20)
14-18 month-olds	0.62 (0.14)	0.60 (0.09)

Table 8. Shape percentage using total number of fixations of Study 3 trials. Means and standard deviations are shown in table.

4.3 Discussion

The current research examined infant processing of form perception in apparent motion stimuli. Although the FFAM-LD/FLAM-LD and FFAM-CD/FLAM-CD conditions did not differ significantly between one another, infants in both conditions displayed significantly more looking to the 2D shape in apparent motion than to the formless random apparent motion. Given denser displays defined solely by luminance or color cues, infants successfully extracted the shape. These results suggest that providing infants with denser dot displays facilitated shape perception in the absence of luminance differences in colored apparent motion stimuli.

Johnson and Aslin (1995) proposed a threshold model of visual development, which posits that perception of objects in the world depend upon both the input of cues in the visual world combined with infants' inherent perceptual skills, or threshold. If the input of cues is sufficient to reach an infant's threshold, then the infant will perceive the object. The results of study 3 align well with this model; when provided with denser dot displays, infants displayed more looking to the shape defined by color differences.

5. GENERAL DISCUSSION AND CONCLUSIONS

Collectively, these three studies examined the roles of color and luminance in infants' perceptions of form in apparent motion stimuli. Studies 1 and 2 both found that infants extracted 2D shape in FFAM stimuli given luminance differences, but showed equal looking to displays defined solely by color differences. Study 3 found that when infants were provided with more information in the displays, they looked significantly more to the FFAM display, suggesting that the dot density increase facilitated the shape percept.

Why, then, was the denser display necessary for infants to exhibit a shape preference in the color-only condition, but not in the conditions in which there were luminance differences? These results might reflect neural pathway separation. Retinal photoreceptors that code color information are termed cones (Sherwood, 2010). Cones sensitive to long (L) and middle (M) wavelengths of light project to both to the magnocelluar pathway (M-pathway) and the parvocellular pathway the (P-pathway) present in the layers of the lateral geniculate nucleus (LGN; Gegenfurtner & Kiper, 2003). The M-pathway is highly involved in the processing of motion, and has projections to the middle-temporal area (MT), also known as visual area V5. This pathway is commonly associated with what is termed in the literature as the dorsal stream, with projections to the visual area V3 as well as MT and the middle-superior-temporal area (MST). In contrast, the P-pathway associated with the ventral stream of processing, and has projections to the visual areas V2, V4 (considered the color complex in much of the literature), and the inferotemporal cortex (Bartels & Zeki, 2000; Hadjikhani, Liu, Dale, Cavanagh, & Tootle, 1998; Hadjikhani & Tootell, 2000).

Neural pathway separation might possibly constitute an underlying mechanism accounting for the present studies' results. The dorsal stream pathway is associated with luminance and motion processing; sometimes it is even referred to as the "where" pathway because of this spatio-temporal information processing. By contrast, the ventral stream pathway is referred to as the "what" pathway, as it is associated with color and form perception. It is possible that the infants in studies 1 and 2 failed to extract the shapes in apparent motion because of the separation of the pathways with different functional specialization areas for color and motion. In line with this possibility, Dobkins and Teller's (1996) work measuring infants' correct performance with color-motion and luminance-motion tasks suggests that while young 2-month-old infants' performance for these tasks is equal, by 4 months of age the performance on luminance-motion tasks is significantly better than performance on color-motion tasks. The infants in the present studies were 11-18 months of age, and likewise showed significantly better performance with FFAM stimuli defined by luminance differences than with FFAM stimuli defined by color differences.

An alternative explanatory model would seek elucidation by considering edge-sensitive vs. edge-insensitive processes (Kellman and Arterberry, 1998). Edge-insensitive processing, the first type considered in this theory that is present at birth, depends on motion and "the position and orientation of the edges or visible parts play no role in determining their completion" (pg 142). This theory states that infants begin with edge-insensitive processing from birth, and that it is adaptive for the visual system to begin processing both space and time discontinuities (before only space discontinuities) because there are fewer ambiguities in perception under conditions with motion-carried information (Arterberry, 2001). In the second half of the first year of life, infants begin edge-sensitive processing. Edge-sensitive processing involves parsing objects in the world based on outlined edges, requiring edge alignment or relatability. Traditionally studied, edge-sensitive processing was considered in static displays in which infants had to use pictorial cues such as interposition, familiar size, shading, or contour to parse objects. In these studies, infants under the age of 6-7 months failed to extract object shapes from these cues alone (Kellman & Arterberry, 2006; Granrud & Yonas, 1984; Tsuruhara, Sawada, Kanazawa, Yamaguchi, and Yonas, 2009, 2010; Bhatt & Waters, 1998). When motion-carried information is added into stimuli that require edge relatability, such as illusory contours, however, infants are able to perceive illusory contours at younger ages (Otsuka & Yamaguchi, 2004; Kavsek & Yonas, 2006). Arterberry (2001) suggests that the edge-sensitive process might have one of two developmental stories: a) a maturational story in which initial motion-carried information sensitivity is combined with later-developing static information sensitivity for the parsing of edges and boundaries or b) that there is an interaction effect in which infants learn about static information edges and boundaries by building on earlier understanding from motion-carried information sensitivity.

Considering both neural pathway separation and edge-insensitive/edge-sensitive processing, it is possible that infants in the color-only conditions were unable to extract shape for two reasons: a) color and motion processing are in separate brain pathways and b) to view shape in the form-from-apparent motion stimuli, the visual system must construct both an illusory contour (a later-developing edge-sensitive process) and motion itself (apparent motion). Previous research suggests that apparent motion is processed in MST, similar to other motion-carried information (Goebel, Khorram-Sefat, Muckli, Hacker, & Singer, 1998; Liu, Slotnick, & Yantis, 2004). Given that infants in all of the conditions had to construct the motion (apparent motion) to extract the shape, having the luminance information accessible in the same dorsal pathway probably contributed to the ease of the task when presented with luminance differences. Color differences, however, are processed in the ventral pathway, and thus requires more of a binding between the pathways for the shape percept. When the dot density in study 3 was increased, the shape percept was facilitated, perhaps allowing for this crucial visual binding. More current research with young infants suggests that 3-month-old infants have similar motion/detection thresholds for color and luminance stimuli; in contrast, adult thresholds for color and luminance stimuli differ greatly (Dobkins, 2009). The infants in the present studies, then, showed a more adult-like pattern of looking, suggesting pathway separation when processing these 2D apparent motion shapes.

In conclusion, the present studies found that infants aged 11-18 months of age can extract 2D shape in FFAM stimuli given luminance differences, as well as given both color and luminance differences. When given only color differences, infants needed denser displays to extract shape. Possible explanations for these results include both neural pathway separation and the ongoing development of edge-insensitive/edge-sensitive processing during infancy. Future research with young infants will provide further insight into the development of these two processes. It is possible that given the color differences FFAM stimuli, young infants with similar color and luminance motion/detection thresholds would extract 2D shape. It is also possible, however, that because these young infants have not yet fully developed edge-sensitive processes, that they would be unable to use the color information to visually bind the area of random-dots colored green into a shape amidst the random dots colored red. Conducting this research would allow further insight into the development of neural pathway separation and edge-insensitive/edge-sensitive processing development.

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